A Quasi-Resonant Quadratic Boost Converter Using a Single Resonant Network

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***Abstract*—This paper presents a quadratic boost converter using a single quasi-resonant network to reach soft commutation. A resonant inductor, a resonant capacitor, and an auxiliary switch form the resonant network and the main switch operates in a zero-current-switching way. A complete analysis of this converter is presented. According to the simulation and experimental results, this quadratic boost converter provides a larger conversion ratio than that provided by the conventional boost converter (for a given duty ratio D), and presents optimum performance, which operates with soft-switch commutation using a single resonant network.**

***Index Terms*—DC–DC power conversion, lossless circuits, resonant power conversion.**

I. INTRODUCTION

NOWADAYS, the utilities and power quality committees demand that the electronic equipment 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. These techniques increase the converter efficiency and switch lifetime.

Quadratic converters [1] operate basically as two conventional converters in cascade; for example, the quadratic boost converter operates as two conventional boost converters in cascade. Therefore, to reach a soft commutation such converters usually use two commutation cells [2], [3]. The main goal of this work is to find a single cell to replace these two cells.

As an extensive research was carried out on the literature, it could be seen that conventional resonant and quasi-resonant converters [4]–[6] provide zero-current switching (ZCS) and/or zero-voltage switching (ZVS) [7], [8] and, therefore, they can operate at high frequencies.

The converter shown in Fig. 1 uses a quasi-resonant network to reach soft commutation (ZCS). Although these techniques have a load limitation, because there are current and/or voltage peaks over the switches, this cell is very suitable in this case, because this converter operates with soft commutation using a single cell.

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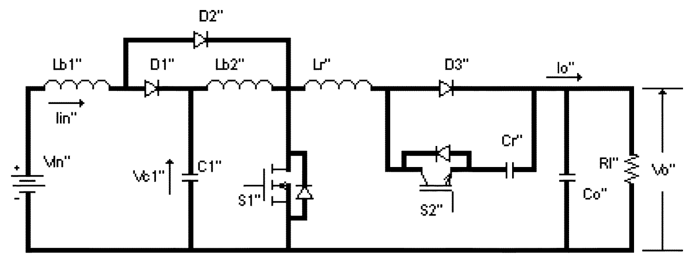


Fig. 1. Quadratic boost converter associated to a quasi-resonant network.

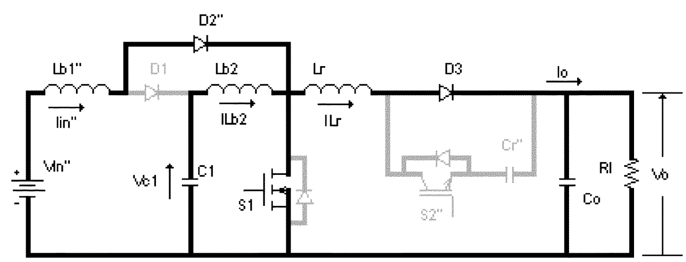


Fig. 2. First stage.

II. PROPOSED QUADRATIC BOOST CONVERTER

The developed converter (Fig. 1) is called a quasi-resonant quadratic boost converter (QR-QBOOST). It employs the resonance principle to achieve the lossless commutation, although it presents inherent pulsewidth-modulation (PWM) characteristics.

One resonant network is added to a quadratic boost converter (corresponding to two boost converters in cascade, where a single active switch is present). A resonant inductor, a resonant capacitor, and an auxiliary switch form the resonant network.

The auxiliary switch operates under ZCS condition because it is placed in series with the resonant inductors. This resonant inductor allows the main switch to operate under ZCS.

III. PRINCIPLE OF OPERATION

To simplify the analysis, the boost inductances L_{b1} and L_{b2} are assumed to be large enough so that they can be considered as ideal current sources I_{in} and I_o, respectively, the voltages across C_1 and C_o present no ripple, all components are treated as being ideal, and the currents I_{in} and I_o flow through diodes D_1 and D_3, respectively, until the main switch is turned on at instant "t_0." According to Fig. 1, six operating stages are described as follows.

First Stage (t_0–t_1)—(Fig. 2). This is the first linear stage. This stage begins when the main switch is turned

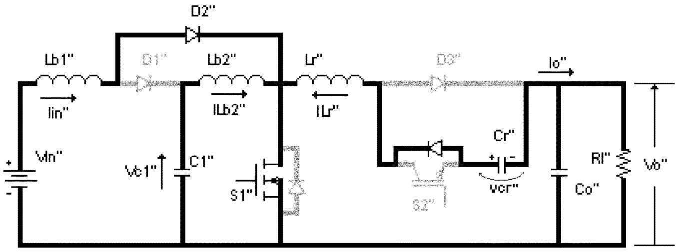


Fig. 3. Second stage.

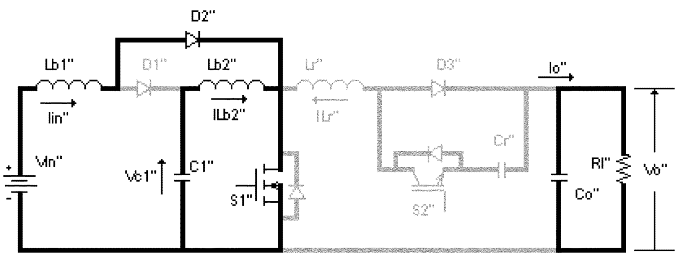


Fig. 4. Third stage.

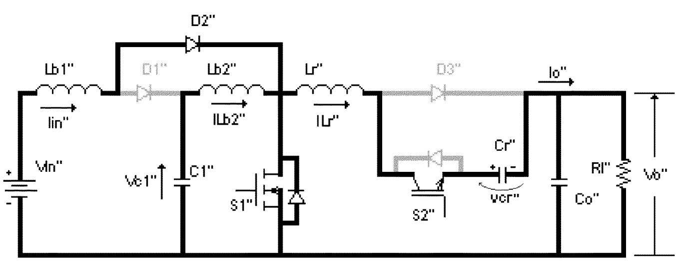


Fig. 5. Fourth stage.

on in a ZCS way. During this stage, the resonant inductor current (I_{Lr}) decreases linearly. This stage finishes when I_{Lr} reaches zero.

Second Stage (t_1–t_2)—(Fig. 3). This is the first resonant stage between resonant inductor L_r and resonant capacitor C_r. In this stage, resonant inductor current I_{Lr} decreases to a minimum value, and then it increases until it reaches zero, when this stage finishes. During this stage C_r is charged up to $2V_o$.

Third Stage (t_2–t_3)—(Fig. 4). This stage is responsible for the PWM characteristics of the converter. It finishes when the switch S_1 is turned off in a ZCS way. During this stage, the input voltage source ($V_{\rm in}$) transfers energy to inductor L_{b1}, while the capacitor C_1 transfers its stored energy to inductor L_{b2}.

Fourth Stage (t_3–t_4)—(Fig. 5). This is the second resonant stage. In this stage I_{Lr} increases to a maximum value, and then decreases until reaches inductor 2 current I_{Lb2}, when this stage finishes. During this stage capacitor C_r is discharged.

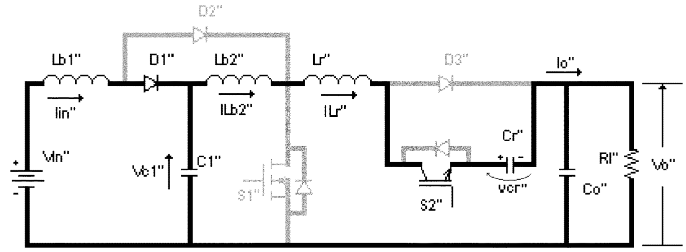


Fig. 6. Fifth stage.

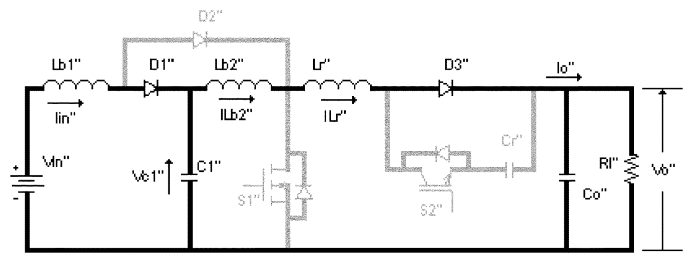


Fig. 7. Sixth stage.

Fifth Stage (t_4–t_5)—(Fig. 6). This is the second linear stage. During this stage inductor L_{b2} discharges capacitor C_r. This stage finishes when capacitor C_r is fully discharged.

Sixth Stage (t_5–t_6)—(Fig. 7). This is the energy delivery stage, where inductor L_{b1} delivers the stored energy to capacitor C_1 and inductor L_{b2} delivers the stored energy to the load. This stage finishes when a new switching cycle begins.

Static gain:
By the energy conservation principle

$$P_o = P_{\rm in} \tag{1}$$
$$V_o i_{omed} = V_{\rm in} I_{\rm in}. \tag{2}$$

The static gain is given by

$$G = \frac{V_o}{V_{\rm in}} = \frac{I_{\rm in}}{i_{omed}}. \tag{3}$$

To calculate the total output average current (iomed) all stages without the third one were analyzed. The output average currents are defined by

$$i_{omed1} = I_{Lb2}\frac{K_1}{2\pi}\left(\frac{\alpha}{2}\right) \tag{4}$$
$$i_{omed2} = I_{Lb2}\frac{K_1}{2\pi}\left(-\frac{2}{\alpha}\right) \tag{5}$$
$$i_{omed4} = I_{Lb2}\frac{K_1}{2\pi}\left(\frac{2}{\alpha} + \sqrt{\left(\frac{1}{\alpha}\right)^2 - 1}\right) \tag{6}$$
$$i_{omed5} = \frac{I_{Lb2}}{T_e}(\Delta T_5) \tag{7}$$
$$i_{omed6} = \frac{I_{Lb2}}{T_s}\left(T_s(1-D) - \Delta T_5\right). \tag{8}$$

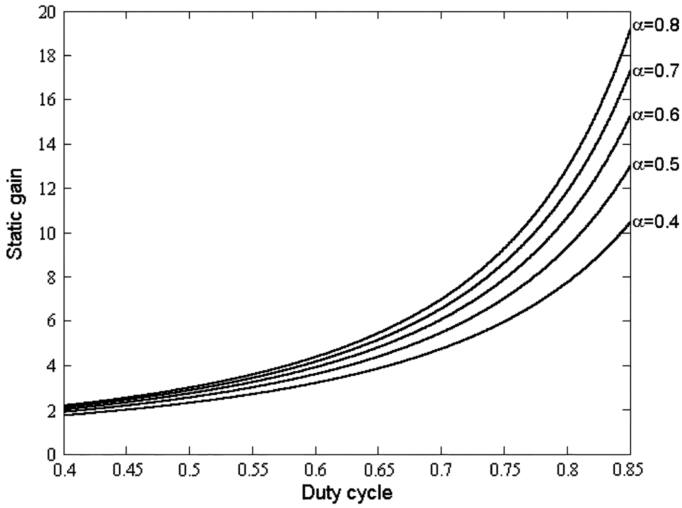


Fig. 8. Static gain.

The total output average current is defined as the sum of the previous equations

$$i_{omed} = I_{Lb2}\left\{1-\left[D+\frac{K_1}{2\pi}\left(\frac{\alpha}{2}+\sqrt{\left(\frac{1}{\alpha}\right)^2-1}\right)\right]\right\} \tag{9}$$

where

$$I_{Lb2} = I_{\text{in}}(1-D). \tag{10}$$

This way

$$G = \frac{V_o}{V_{\text{in}}} = \left\{\frac{1}{1-\left\{D+\frac{K_1}{2\pi}\left[\frac{\alpha}{2}+\sqrt{\left(\frac{1}{\alpha}\right)^2-1}\right]\right\}}\right\}^2 \tag{11}$$

where

$$k1 = \frac{f_s}{f_o} \tag{12}$$

$$\alpha = \frac{I_{Lb2}}{V_o}\sqrt{\frac{L_r}{C_r}} \tag{13}$$

where

- I_{Lb2} current in $Lb2$;
- V_{in} input voltage;
- V_o Output voltage;
- D duty cycle;
- f_s switching frequency;
- f_o resonant frequency.

The static gain graph is shown in Fig. 8.

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

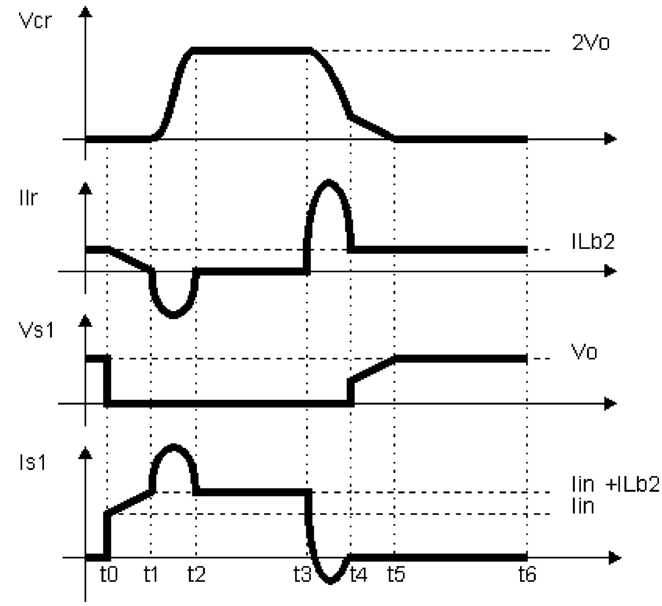


Fig. 9. Theoretical waveforms obtained for the QBOOST-PWM-ZVS-SR converter.

IV. Simulation and Experimental Results

The boost converter associated to the soft commutation circuitry (Fig. 1) was analyzed by simulation carried out on PSpice software, where the following parameter set was used:

$$\begin{aligned} &S_1 = \text{IrfP460} && S_2 = \text{ideal} && \text{Diodes} = \text{ideal}\\ &C_1 = 100\ \mu\text{F} && C_o = 100\ \mu\text{F} && L_{b1} = 300\ \mu\text{H}\\ &L_{b2} = 300\ \mu\text{H} && L_r = 0.6\ \mu\text{H} && C_r = 90\ \text{nF}\\ &V_{\text{in}} = 20\ \text{V} && V_o = 130\ \text{V} && P_o = 250\ \text{W}. \end{aligned}$$

A prototype of the proposed SSQBOOST was then built using the following parameter set:

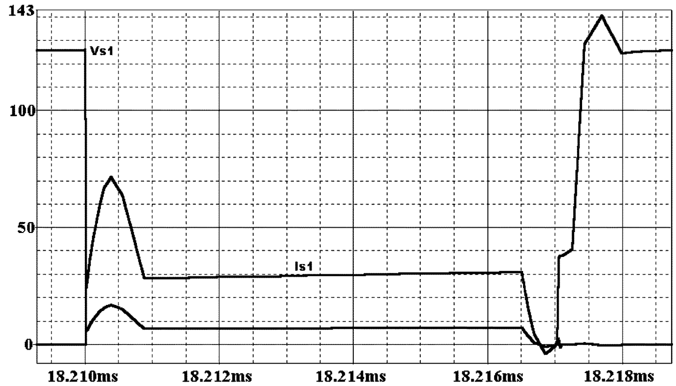
$$\begin{aligned} S_1 &= 2\times\text{IrfP460} && SD_2 = \text{IRGBC20FD2}\\ D_1 \text{ and } D_2 &= 2\times\text{30tb60} && D_3 = \text{MUR1560}\\ C_1 &= 100\ \mu\text{F}; && C_o = 100\ \mu\text{F}\\ L_{b1} &= 300\ \mu\text{H} && L_{b2} = 300\ \mu\text{H}\\ L_r &= 0.6\ \mu\text{H} && C_r = 90\ \text{nF}\\ V_{\text{in}} &= 20\ \text{V} && V_o = 150\ \text{V}\\ P_o &= 250\ \text{W}. \end{aligned}$$

Figs. 10–13 show the simulation and experimental results.

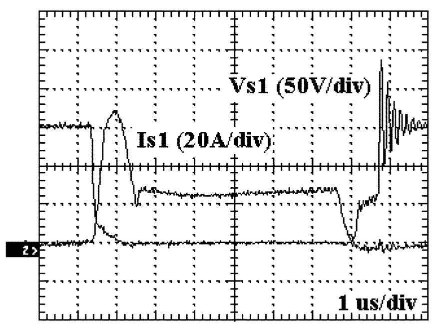
Figs. 10 and 11 show the active switches commutations. It can be seen that the main switch commutations are nondissipative. The auxiliary switch commutates under zero-current condition. Therefore, the commutations are lossless.

Fig. 12 shows the current in inductors L_{b1} and L_{b2}. The small oscillation is due to the inductance value.

Fig. 13 shows the voltage step up obtained with the proposed circuit. As expected, one can see that input voltage increases in the converter.

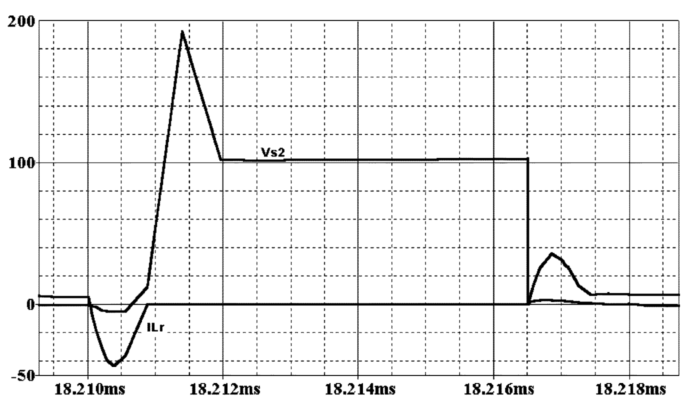


(a)

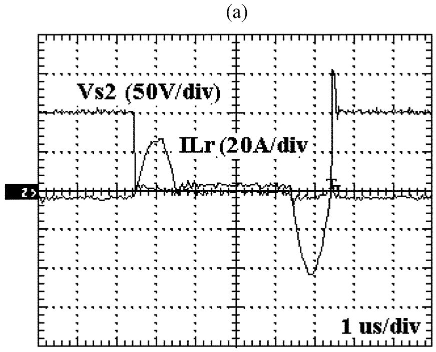


(b)

Fig. 10. Main switch (S1) waveforms for (a) simulation results and (b) experimental results under nominal load (250 W).

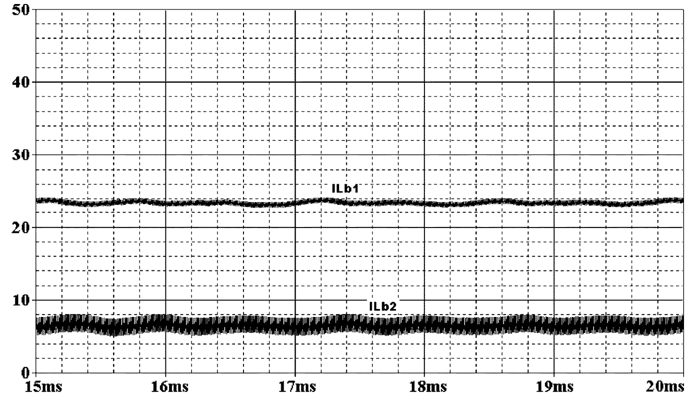


(a)

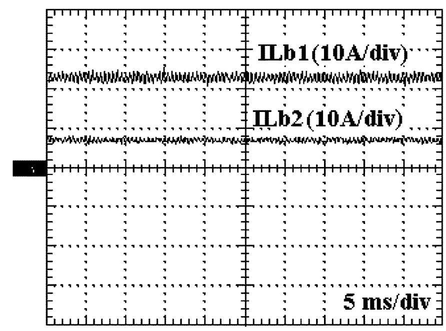


(b)

Fig. 11. Auxiliary switch (S2) waveforms for (a) simulation results and (b) experimental results under nominal load (250 W).

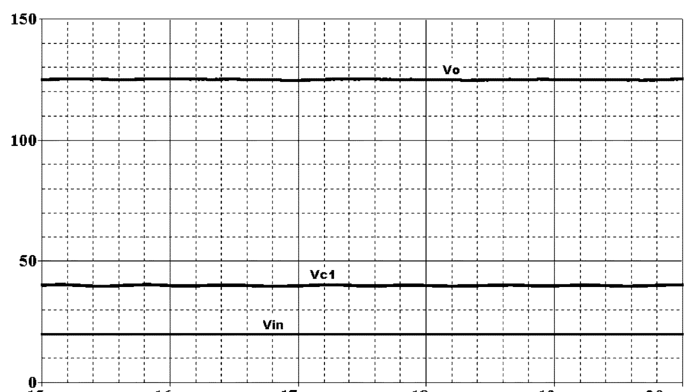


(a)

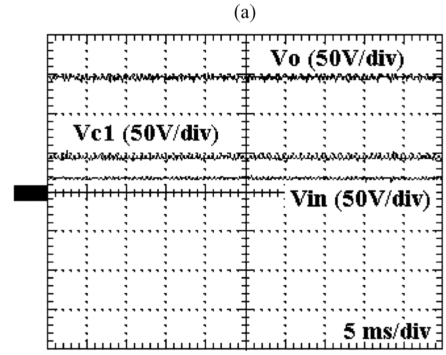


(b)

Fig. 12. Current in inductors Lb1 and Lb2: (a) simulation results and (b) experimental results under nominal load (250 W).



(a)



(b)

Fig. 13. Input voltage, output voltage, and average voltage. (a) Simulation results. (b) Experimental results under nominal load (250 W).

Fig. 14 shows the efficiency of prototype with and without the resonant cell. The efficiency of the prototype with resonant cell achieved 98% and without the resonant cell it achieved only 94%, at full load (250 W).

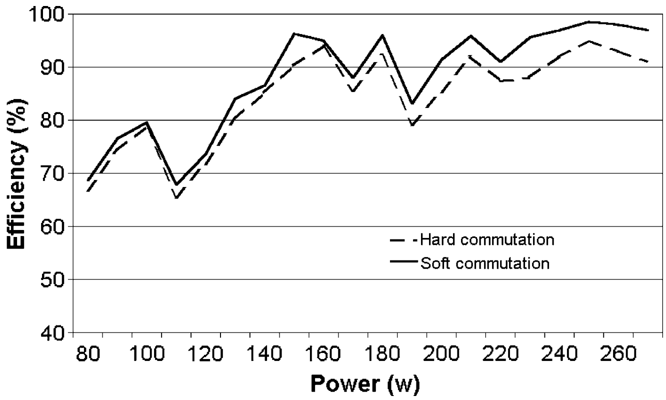


Fig. 14. Prototype efficiency.

V. Conclusion

According to the study presented in this paper, the simulation and experimental results demonstrate the QR-QBOOST presented optimum performance, which operates with soft-switch commutation using a single resonant network.

For a given duty ratio D, the quadratic converter provides a larger conversion ratio than that provided by the conventional PWM converter.

The proposed study combines the quasi-resonant characteristics and the PWM characteristics in a single converter, which operates with lossless commutation in a ZCS way and controls the output power varying the duty cycle in switch S_1.

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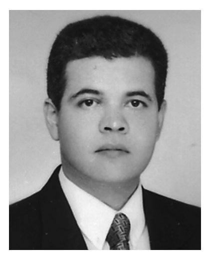

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