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Comparison Analysis of Boost Chopper with Various Snubber Circuits

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Abstract: This study describes DC chopper with Boost and Boost-ZVT with various circuit configuration. Several snubber circuits are connected with the chopper aiming at enhancing the output performance in term of voltage, power and minimizing the chopper losses. The analysis is based on building the mathematical model, the simulation circuits and processing the results using PSIM and Matlab environment. The results varies in wide range according to the applied circuits where the worst case is inherent to the simple boost circuit while the optimized results are obtained when a specified snubber circuit is connected to the main converter circuit.

Key words: DC-DC converters, soft-switching, high frequency power converters, pulse width modulation, power electronics, buck-boost choppers

INTRODUCTION

The DC-DC converters are widely used in regulated switch mode power supplies. The input voltage to these converters varies in wide range especially in the case of photovoltaic supply source where the sun irradiations varies according to the weather and seasons changes.

Therefore, the input of these converters is an unregulated voltage while the output voltage must be kept at minimum fluctuations and ripples (Lin and Huang, 2009; Dias *et al.*, 2009; Woywode and Guldner, 2000).

From the energy point of view, output voltage regulations in the DC-DC converters is achieved by continuously adjusting the amount of the energy absorbed from the source and that injected in the load which is in turn can be achieved by controlling the time intervals of energy absorption and energy injection in the circuit. These two basic processes of energy absorption and injection constitute a switching cycle presented as duty cycle of operation D. There are two operation modes known as Current Continuous Mode (CCM) and Current Discontinuous Mode (DCM).

Several methods and techniques were applied aiming at regulating the Duty cycle D of the chopper with purpose to reduce the voltage ripples and to maintain the output voltage at minimized switching looses of the chopper. Pulse Width Modulated (PWM) converters are required to operate with high frequency due to demand for high power density with reduced switching looses by using so called soft switching techniques (Moschopolous and Huang, 2006; Jean *et al.*, 2001; Abu-Qahouq and Bataresh, 2000). Realizing this aim can be achieved by applying Zero-Voltage Switching (ZVC) in the main switching circuit with an active auxiliary circuit that is activated just before the main switch is to be turned on and is deactivated sometime afterward. The auxiliary circuit consists of an active switch (IGBT) and passive elements such as inductances and capacitances that have lower ratings than those in the main power circuit as the auxiliary circuit is activate for only a fraction of a switching cycle.

PWM converters with such circuits are referred to Zero Voltage Transitions (ZVT) PWM in the literatur (Robbins, 2008; Hart, 2010). The auxiliary circuits can either be non-resonant circuit with a switch with a hard turn-off as or a resonant circuit with LC resonant components that allow the switch to have a soft turn-off but at the expense of increasing the circulating current.

MATERIALS AND METHODS

Mathematical modeling: The methodology and mathematical modeling will be described in two stages, first, modeling of boost converter in various current conduction modes and then analyzing the circuit performances when auxiliary or cascade circuit is added. Principle electrical circuit for Boost converter is shown in Fig. 1 where the main switch is connected in parallel with

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the source throughout inductor in order to step-up the output voltage. This circuit can be operated in both current conduction modes.

Conversion modes: The DC-DC converter has two operation modes CCM and DCM it is obviously CCM is applied for efficient power conversion while the DCM is for Lower power and stand-by applications.

Continuous conduction mode: This mode has two operation intervals depending on the duty cycle, first interval has a time of ($0<t\leq t_{on} = D.T_s$) where the switch conducts during this interval and the inductor accumulate storage energy.

The equivalent circuit for this interval is shown in Fig. 2a while the second interval has a time of ($t_{on}<t\leq T_s$) with equivalent circuit shown in Fig. 2b by assuming that the inductor has large value and ramp up linearly. The integral of inductor voltage over a time period in steady state conditions can be expressed as follows:

$$Vst_{on} + (V_s - V_o)t_{off} = 0$$

Than

$$Vo = \frac{T_s}{t - off} = \frac{1}{1 - D}\ Vs;\ D > 0 \qquad (1)$$

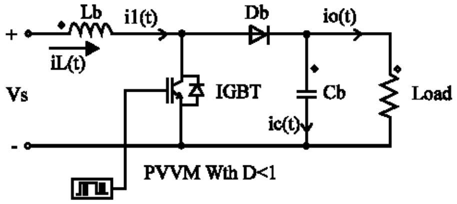


Fig. 1: Step-up Boost Converter (Abu-Qahouq and Bataresh, 2000)

Where:

V_s = The input voltage
V_o = The output voltage
T-on = The switching-on time
t-off = The switching-off time
T_s = The switching period, respectively

Discontinuous conduction mode: This mode is characterized with three current intervals: current rising up, current falling down and zero current intervals as well shown in Fig. 3 where the integral of the inductor voltage can be expressed as follows:

$$Vs\,D\,T_s + (Vs - V_o)\,D_1 T_s = 0$$

Then

$$V_o = \frac{D_1 + D}{D_1} Vs \qquad (2)$$

With purpose to hold Vo constant by varying D in response to variations in Vs, the duty cycle is represented as function of the load current as follows:

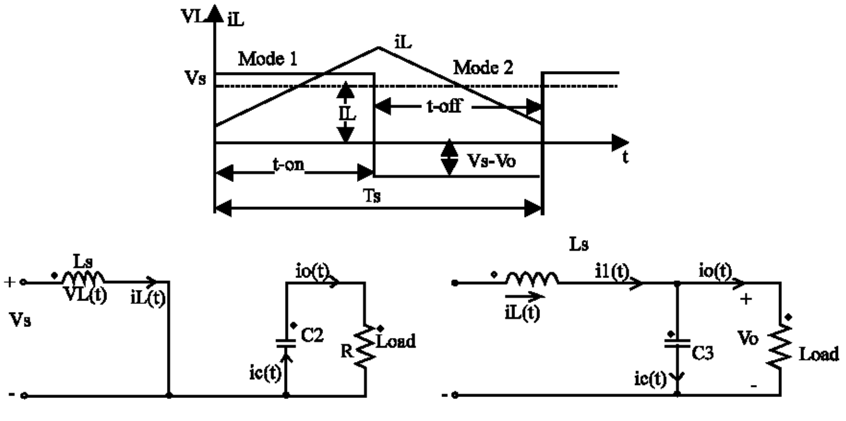
$$D = \left[\frac{4}{27}\frac{V_o}{Vs}\left(\frac{V_o}{Vs} - 1\right)\frac{I_o}{I_{oAV}}\right]$$

Where,

$$I_{oAV} = \frac{T_s V_o}{2L_b} D(1-D)^2 \qquad (3)$$

Where

D_1 = The duty cycle corresponds to the time until i_1 falls to zero value and ($D+D_1$). $Ts<T_S$ presents $mode_3$
L_b = The boost inductance and
I_{OAV} = The average load current



(a) mode 1

(b) mode 2

Fig. 2: Equivalent circuit for boost converter operating in CCM

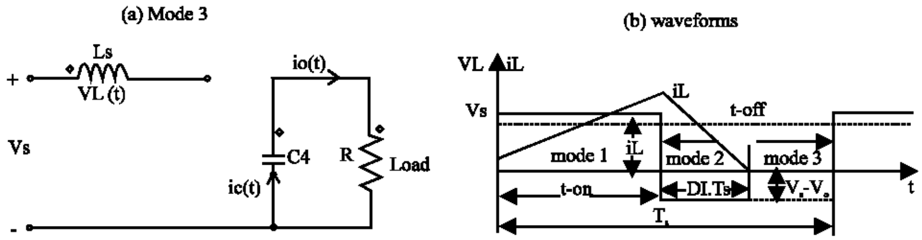


Fig. 3: Equivalent circuit for boost converter operating in DCM

According to Jean *et al*. (2001), Abu-Qahouq and Batarseh (2000) and Hart (2010) the boundary value of the inductance required to maintain the current at CCM and the capacitance for minimizing the voltage ripples, taking into account Eq. 1 and 3 can be expressed as follows:

$$L_{b\min} \ge \frac{R\times D(1-D)^2}{2\times f_s} \text{ and } C_{b\min} \ge \frac{V_o\times D}{f_s\Delta V_o\times R} \qquad (4)$$

Where:

R = The load resistance

F_S = The switching frequency

ΔV_O = The voltage ripples

RESULTS AND DISCUSSION

Simulation results: Simulation results has been obtained using PSIM and Matlab software tools where the inductor and output voltage are simulated at D = 45% and the results are shown in Fig. 4 for L_b of 20 mH that realizing CCM and L_b of 2 mH for DCM at C_b of 2000 µF. Different circuit have been studied with respect to transisotr losses, current ripples and voltag stability as follows:

Auxiliary circuits: In order to reduce the switch losses, and to reduce the output voltage dependency on the variations of input voltage an auxiliary circuit in ZVT-PWM converter is generally placed parallel to the main power switch as well shown in Fig. 5. This circuit forces the voltage across the main switch to drop to zero before it is turned on so that it can do so with reduced losses.

The active switch in the auxiliary circuit is a device that can be turn-on with fewer switching losses than the main switch (Woywode and Guldner, 2000; Moschopolous and Huang, 2006). Several designed circuits and configurations are examined with purpose to select the appropriate circuit with optimized performances.

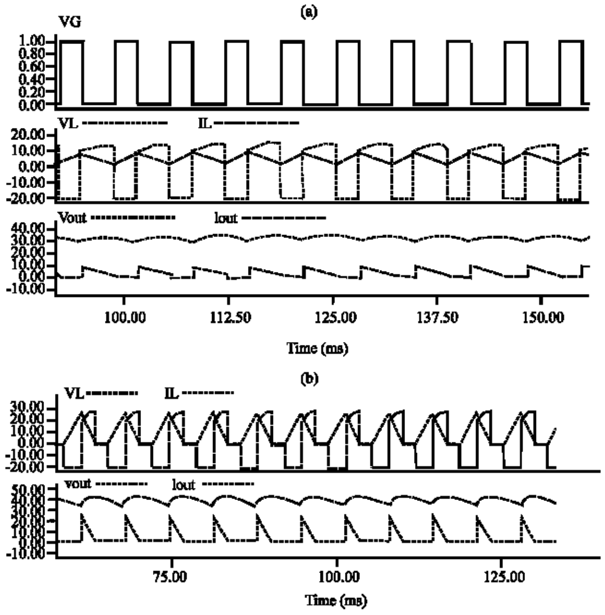


Fig. 4: Circuit voltages and currents at (a) CCM and (b) DCM conduction mode

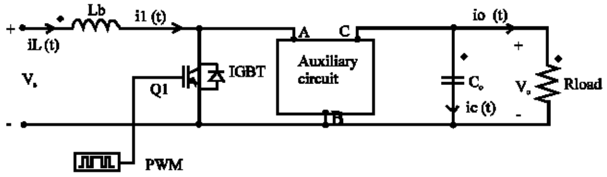
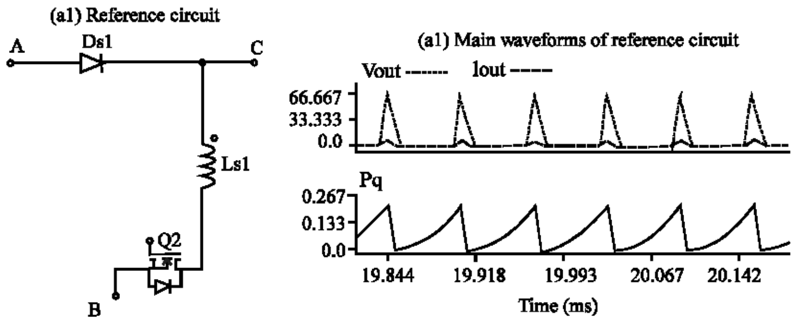


Fig. 5: General circuit of a ZVT-PWM DC-DC boost converter (Jeam *et al*., 2001)

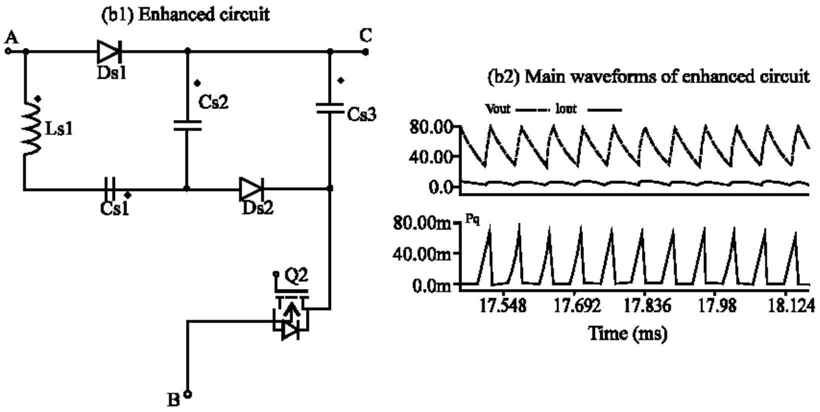
Simulation of auxiliary circuits using PSIM: Some of these circuits are shown in Fig. 6 with corresponds load voltage, current and transistor losses. From these load voltage, current and minimized switching losses. These circuits are shown in Fig. 6 (d_1 and e_1) and respectively their waveforms shown in Fig. 6 (d_2, e_2).

Figure 7 shows the output voltage as function of the modulation index for three circuit:basic/reference circuit (Fig. 6a_1), cascade circuit (Fig. 6d_1) and auxiliary snubber circuit (Fig. 6e_1) where cascade circuit and auxiliary circuits have acceptable performances for $0.1 \le Ma \le 0.9$ which corresponds to duty cycle of $0.1 \le D \le 0.9$.



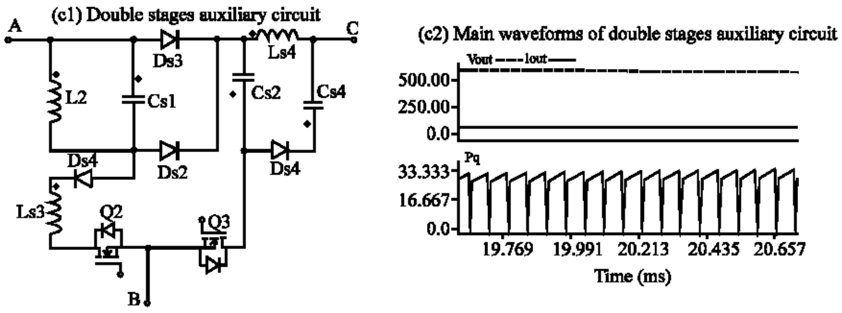
(a1) Reference circuit

(a1) Main waveforms of reference circuit



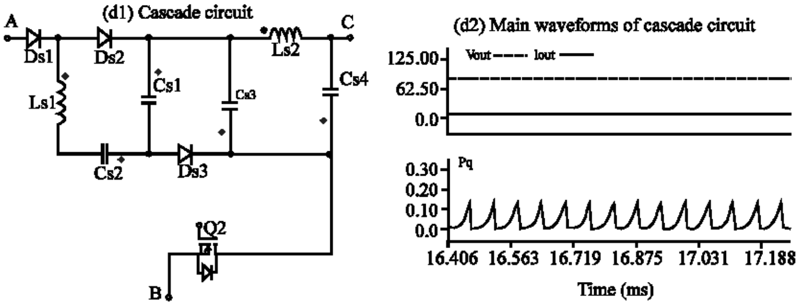
(b1) Enhanced circuit

(b2) Main waveforms of enhanced circuit



(c1) Double stages auxiliary circuit

(c2) Main waveforms of double stages auxiliary circuit



(d1) Cascade circuit

(d2) Main waveforms of cascade circuit

Fig. 6: Continue

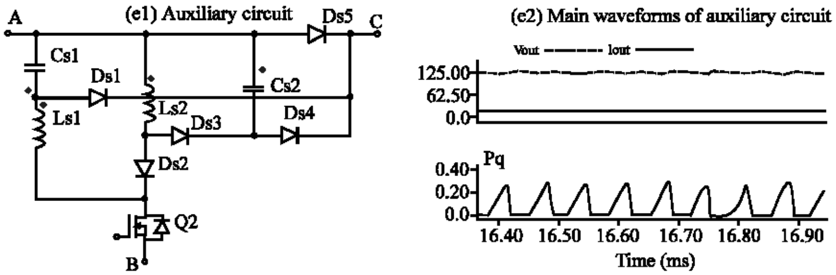


Fig. 6: Auxiliary and cascade circuits and their corresponding waveforms

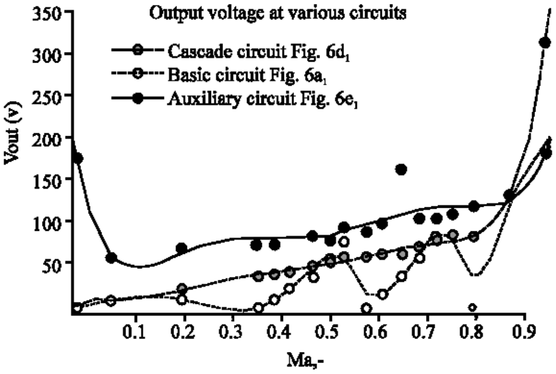


Fig. 7: Output voltage of reference, cascade and auxiliary circuits

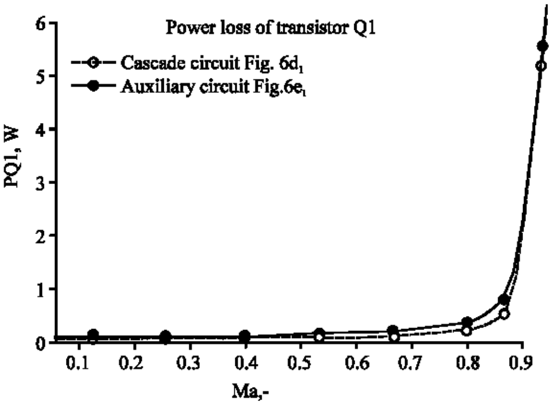


Fig. 8: Power losses of transistor Q1

shown that with respect to losses both circuits have similar loss rate to some extent. Therefore, there is a need to analysis how the output voltage will change with input voltage variations.

This relation is shown on Figure 9 for both circuits whereas cascade circuit less reacts to the input voltage change comparing with auxiliary circuit.

Therefore, it can be conclude that cascade circuit presents better performances comparing with auxiliary snubber circuit.

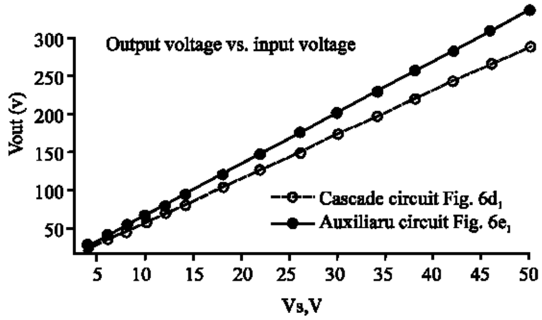


Fig. 9: Output voltage vs input voltage at cascade and auxiliary circuit

CONCLUSION

This study concern with design and simulation of DC-DC boost converter with various circuit configurations. From the obtained results and their analysis, the following are the salient conclusions that can be drawn.

Studying the converter operation regimes and how the current operation mode can be controlled. Proposing of various boost converter circuits where comparison analysis has been realized. ZVT-PWM techniques have been implemented with purpose to reduce the switch losses and the output voltage ripples. Cascade circuit is characterized with more stability with respect to duty cycle control.

The PWM control of these circuits can be operated through feedback signal generated from both, the source and load side aiming at realizing more stability on the output. This will be presented in coming study with photovoltaic prototype verifications. Because of the input voltage fluctuation, This design can be used in photovoltaic systems and applications.

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