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International Journal of Engineering & Technology, 7 (4.30) (2018) 246-252

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Research paper

Implementation of Resonant and Passive Lossless Snubber Circuits for DC-DC Boost Converter

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Abstract

This paper presents the comparison of resonant and passive lossless snubber circuits implementation for DC-DC boost converter to achieve soft-switching condition. By applying high switching frequency, the volume reduction of passive component can be achieved. However, the required of high switching frequency cause the switching loss during turn-ON and turn-OFF condition. In order to reduce the switching loss, soft-switching technique is required in order to reduce or eliminate the losses at switching devices. There are various of soft-switching techniques can be considered, either to reduce the switching loss during turn-ON only, or turn-OFF only, or both. This paper discusses comparative analyses of resonant and passive lossless snubber circuits which applied in the DC-DC boost converter structure. Based on the simulation results, the switching loss is approximately eliminated by applying soft-switching technique compared to the hard-switching technique implementation. The results show that the efficiency of resonant circuit and passive lossless snubber circuit are 82.99% and 99.24%, respectively. Therefore, by applying passive lossless snubber circuit in the DC-DC boost converter, the efficiency of the converter is greatly increased. Due to the existing of an additional capacitor in soft-switching circuit, it realizes lossless operation of DC-DC boost converter.

Keywords: *DC-DC Boost Converter; Passive Lossless Snubber; Resonant; Soft-Switching; Switching Frequency.*

1. Introduction

Nowadays, transportation has become one of the most important things to move from one place to another. However, due to the large number of automobile in a big city around the world, it has become the most critical issues which arise a pollution problem and may affect the environment and also to the human life [1][2]. To overcome this problem, the world today is approaching to the green transportation, such as electric vehicles (EVs). Due to the high voltage across the DC-link busbar (200 V – 400 V), it is difficult for the designer of EV system to integrate the power storage with the electric traction part. Thus, the system needs a power converter as an interface which has capability to handle the energy transfer from 12-48 V DC bus to the high voltage DC-link busbar. DC-DC boost converters become the main key blocks inside the EV system in order to process the energy from input to the output side [3][4]. Due to limitation space and weight in EV system, the optimization design of DC-DC boost converter is required.

By increasing the switching frequency of the converter, it may have become the best option in order to reduce the volume of passive component and the total volume of converter. This is because the volume of DC-DC boost converter is mostly contributed by the passive components i.e., inductor and heatsinks. Thus, to reduce the design of boost inductor, high switching frequency is applied to reduce the charging and discharging time of inductor. So, the optimum inductance can be design [5][6].

However, the increasing of switching frequency in power converter may reduce the efficiency of converter due to the losses in switching devices is proportion to the switching frequency. Thus, soft-switching technique is required in order to reduce or eliminate the switching loss in switching devices [7]–[11]. Soft-switching consist of several technique where it follows the application suitability. By comparing the resonant and passive lossless snubber circuits, this paper analyzes the performance of the designed converter in terms of efficiency which techniques are suitable for EV application.

This paper focuses on how the increasing efficiency of DC-DC boost converter can be realized by using resonant circuit and passive lossless snubber circuit. The analyses and discussion are made in order to compare which technique of soft-switching technique is suitable for EV applications. The simulation results are clarified in order to verify the effectiveness of soft-switching techniques.

2. DC-DC Boost Converter Parameters Design

Several parameters are required for designing DC-DC boost converter i.e., boost ratio β, output voltage V_{out}, boost inductor L_{boost}, and output capacitor C_{out} where the equation as pointed in (1) to (4). The current ripple ΔI_L and the voltage ripple ΔV_{Cout} are considered in order to appropriately select the inductor and capacitor, respectively [2][5][6]. The design of parameter in DC-DC boost converter ensure the circuit operate in Continuous Conduction Mode (CCM).

$$\beta = \frac{1}{1-D} \quad (1)$$

$$V_{out} = \frac{V_{in}}{1-D} \quad (2)$$

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$$L_{boost} = \frac{DV_{out}}{2 f_{sw} \Delta I_{Lboost}} \tag{3}$$

$$C_{out} = \frac{DP_{out}}{f_{sw} V_{out} \Delta V_{Cout}} \tag{4}$$

3. Typical hard-switching technique principle in DC-DC boost converter

The switching device in DC-DC boost converter circuit required a signal in order to control the switch to turn-ON and turn-OFF. This signal is crucial in order to control the switch and flow the current of the circuit to charge and discharge the boost-up energy to the output side. Figure 1 shows the circuit structure of DC-DC boost converter which consist of one switching device S and one diode D. Figure 2 shows the PWM switching pattern where the square waveform is develop by comparing triangular carrier waveform and straight line as the duty cycle. Two operation modes in one full complete cycle, i.e., Mode 1 (S in turn-ON), Mode 2 (S in turn-OFF).

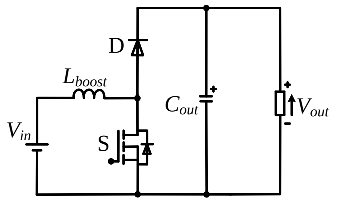


Fig. 1: Circuit structure of DC-DC boost converter

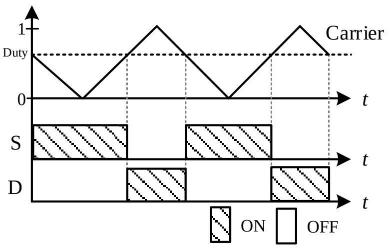


Fig. 2: PWM switching pattern

3.1. Semiconductor losses in hard-switching

Generally, semiconductor device can be switching device or diode. In semiconductor losses, it consists of switching loss and conduction loss for switching device, meanwhile only conduction loss for diode. Basically, the switching loss in hard-switching technique occur due to the overlapping of current and voltage at switching device. Basically, the area of overlapping will large as the switching frequency increasing. This causes the switching loss greater when high switching frequency is applied.

Figure 3 shows the overlapping of current and voltage which produce switching loss during turn-ON condition. The current flow in switching device known as I_{ds}, meanwhile the voltage across switching device can also known as V_{ds}. Usually, the switching loss is calculated in terms of power P_{sw} as in equation (1). The area of switching loss is large when the overlapping between current I_{ds} and voltage V_{ds} is large. This can affect the efficiency of DC-DC boost converter reduce. The conduction loss in switching device is depend on the ON-resistance R_{on} which consist in switching device. This parasitic resistance causes the current flow in the R_{on} during the turn-OFF condition of switching device. Practically, the conduction loss in switching device cannot be eliminated due to the R_{on} is built in the switching device. However, it can be reduced by selecting the low rating or small R_{on} in switching device. The conduction loss in switching device $P_{cond(m)}$ can be calculated by using equation as pointed in (2). Meanwhile, the conduction loss in diode $P_{cond(d)}$ can be calculated by using equation as pointed in (3). The conduction loss basically is not related to the switching frequency applied in the switching device.

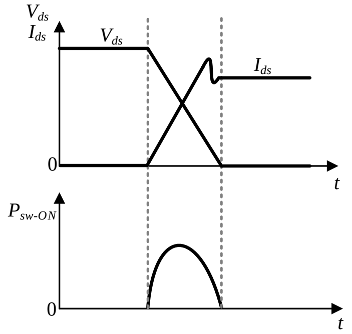


Fig. 3: Overlapping of I_{ds} and V_{ds} during turn-ON condition

$$P_{sw} = \left[\frac{(I_{ds} V_{ds}) \times (t_r + t_f)}{6} \right] (f_{sw}) \tag{5}$$

$$P_{cond(m)} = I_{ds}^{2} \times R_{ON} \times D \tag{6}$$

$$P_{cond(d)} = I_{F(rms)} \times V_f \tag{7}$$

4. Soft-switching technique implementation in DC-DC boost converter

Aforementioned, the soft-switching technique is applied in order to reduce the switching loss at switching devices due to high switching frequency is utilized. The concept of soft-switching basically is to prevent the overlapping of current I_{ds} and voltage V_{ds} at switching devices. By considering the applications as mentioned in the introduction, the soft-switching technique must be reliable and simple. Thus, Zero Voltage Switching Quasi-Resonant (ZVS QR) circuit and passive lossless snubber circuit is selected as for the comparative analyses in this paper. This is because these two soft-switching techniques do not require any additional control circuits which increases complexity of the circuit.

4.1. ZVS quasi-resonant circuit

Resonant circuits are commonly used in DC-DC boost converter due to the excellent performance of eliminate the switching loss in switching device. Basically, there are two conditions of soft-switching in resonant converter which are during turn-ON and turn-OFF. Zero Voltage Switching (ZVS) during turn-ON can be realized when the resonant inductor C_r is connected in parallel with the switching device [12]. The ZVS condition is achieved when the drain source voltage V_{ds} is zero before the drain source current I_{ds} in switching device rise. Meanwhile, Zero Current Switching (ZCS) during turn-OFF is realized by connecting the resonant inductor L_r in series with the switching device. The ZCS condition is achieved when the drain source current fall to zero before the drain source voltage is rise. These two conditions are aim to avoid the overlapping between drain source current and drain source voltage, so the switching loss is not occurred. Figure 4 shows the illustration of drain source voltage and drain source current in ZVS and ZCS conditions where produce no losses for resonant converter. However, in this paper, ZVS QR circuit is consider due to the difficulty to realize ZCS condition in the converter.

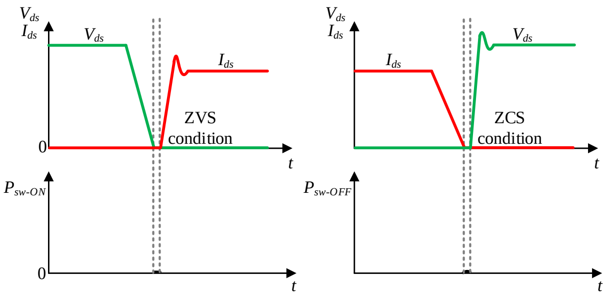


Fig. 4: The illustration of ZVS and ZCS condition during turn-ON and turn-OFF by using resonant circuit

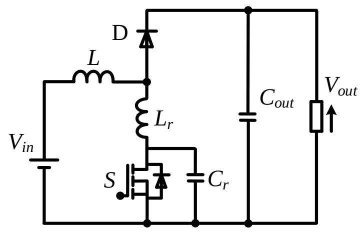


Fig. 5: DC-DC boost converter with resonant circuit [11]

4.1.1. Design of ZVS quasi-resonant circuit

To design the ZVS QR circuit in DC-DC boost converter, there have several parameters that required to consider. This parameter is important in order to get a suitable value of resonance inductor and resonance capacitor. ZVS QR half-wave converter is consider due to the utilize of MOSFET as the switching device. Firstly, the output resistance R_{out} must be obtained, thus it can be expressed as follows:

$$R_{out} = \frac{V_{out}{}^{2}}{P_{out}} \tag{8}$$

Next, after the load has been identified, the output current I_{out} can be obtained through this expression:

$$I_{out} = \frac{V_{out}}{R_{out}} \tag{9}$$

By assuming this 2-level CBC is lossless where the input power is same with the output power, then the DC voltage transfer function M_{VDC} can be expressed as follows:

$$M_{VDC} = \frac{V_{out}}{V_{in}} \tag{10}$$

After that, due to the utilize of MOSFET, the half-wave ZVS converter ($h \leq 0$) is consider where can let $n = 1$, $Q = M_{VDC}$ and set the switching frequency f_s. By refer to Figure 6, if the f_s/f_o is satisfied with the value that referred in the DC voltage transfer function, the resonant frequency can be obtained as follows:

$$f_0 = \frac{M_{VDC} \times f_s}{1.1} \tag{11}$$

Next, obtain the characteristics impedance Z_0 of resonant circuit which can be expressed as follows:

$$Z_0 = \frac{R_{out}}{Q} \tag{12}$$

Hence, the duty cycle at $h = 0$ can be proven from this expression:

$$h = \pm\sqrt{1-\left(\frac{Q}{M}\right)^2} \tag{13}$$

After the duty cycle is verified at $h = 0$, the duty cycle can be calculated and can be expressed as follows:

$$D = 1 - 0.9092 \times \left(\frac{f_s}{f_o}\right) \tag{14}$$

Thus, the resonant inductance and resonant capacitance can be obtained where can be expressed as follows:

$$L_r = \left(\frac{R_L}{\omega_0 Q}\right) \tag{15}$$

$$C_r = \left(\frac{Q}{\omega_0 R_{out}}\right) \tag{16}$$

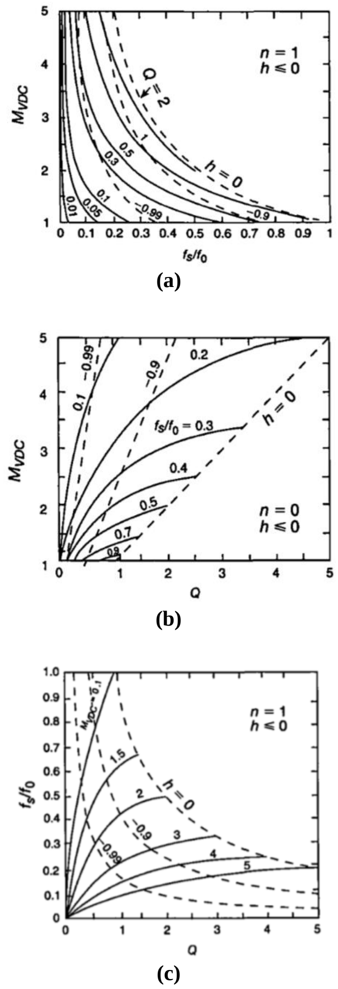


Fig. 6: DC voltage transfer function for boost ZVS QR circuit at $n = 1$ for half-wave converter [11][12]

4.2. Passive lossless snubber circuit

Conventionally, passive snubber causes the degradation of the output power of the converter due to the energy in the circuit is required to charge and discharge the snubber circuit [13][14]. Then, passive lossless snubber is developed in order to overcome the problem degradation of output voltage [10], [15]–[17]. The existing of the buffer capacitor in passive lossless snubber circuit solve the degradation of output voltage in the conventional passive snubber. The circuit structure of passive lossless snubber circuit consisting of snubber inductor L_s, snubber capacitor C_s, buffer capacitor C_r, and snubber diode D_{s1}, D_{s2}, D_{s3}. Figure 7 shows the ZCS and ZVS condition during turn-ON and turn-OFF if passive lossless snubber circuit is used. Figure 8 shows the circuit structure of DC-DC boost converter with passive lossless snubber circuit.

Basically, passive lossless snubber circuit have a different term of soft-switching during turn-ON and turn-OFF if compared to ZVS QR. In order to achieve soft-switching during turn-ON, snubber inductor is used in order to slowing down the drain source current from rise. Thus, this will provide soft turn-ON condition or ZCS turn-ON. Meanwhile, the snubber capacitor is used in order to achieve soft turn-OFF or ZVS turn-OFF by slowing down the drain source voltage from increasing during the switching device turn-OFF. Obviously, resonant inductor L_r and resonant capacitor C_r in ZVS QR are used in order to achieve soft-switching during turn-ON and turn-OFF condition, respectively. Meanwhile, snubber inductor L_s and snubber capacitor C_s in passive lossless snubber circuit are used to realize the soft-switching during turn-ON and turn-OFF, respectively.

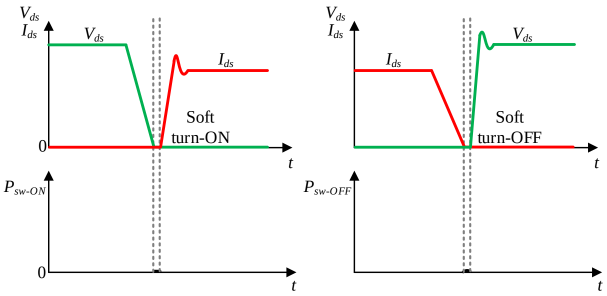


Fig. 7: ZCS and ZVS condition during turn-ON and turn-OFF for passive lossless snubber

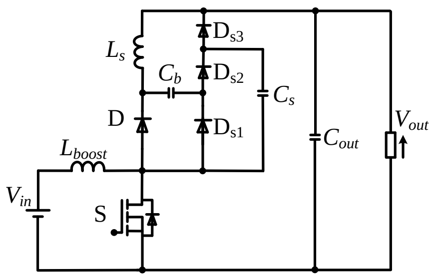


Fig. 8: DC-DC boost converter with passive lossless snubber circuit [16]

4.2.1. Design of passive lossless snubber circuit

In order to identify the value of snubber circuit of DC-DC boost converter, several parameters are required to obtain. T. Principally, the value of snubber inductor and snubber capacitor must be combined in a one resonant frequency where it can be expressed as follows:

$$\omega_r = \frac{1}{\sqrt{L_s C_s}} \tag{17}$$

Then, the current range (I_{min} and I_{max}) of switching device must be obtained to ensure the soft-switching can be achieved. The maximum current of semiconductor device can be expressed as follows:

$$I_{\max} = \frac{P_{in}}{V_{in-\min}} \tag{18}$$

$$I_{\min} = \frac{P_{in}}{V_{in-\max}} \tag{19}$$

Next, the range of duty cycle (D_{min} and D_{max}) is calculate to ensure the minimum and maximum duty cycle where the soft-switching occur. The minimum and maximum duty cycle can be expressed as follows:

$$D_{\min} = 1 - \frac{V_{in-\max}}{V_{out}} \tag{20}$$

$$D_{\max} = 1 - \frac{V_{in-\min}}{V_{out}} \tag{21}$$

By relating the inductance and capacitance snubbers with the resonant interval times where it can be suggested less than some fraction ($0 < k < 1$) of the switching period T_s. Thus, this relation can be expressed as follows:

$$\frac{2\pi}{\omega_r} \le kT_s \tag{22}$$

where the appropriate value of k is selected for a required T_{r-on} or T_{r-off}. The value of k is select by refer to the Figure 5 where the smallest value of k is selected and which satisfies the largest allowable value of T_{r-on} and T_{r-off}. From Figure 5, IR is the current ratio of maximum current and minimum current. Meanwhile, x is the ratio of snubber capacitor and buffer capacitor which can be equate by 0.1. The detail of design principle is given in the paper [15][16]. The interval for T_{r-on} is $I = I_{max}$ where it represents the worst case, meanwhile for T_{r-off} interval, several current ratios are shown in Figure 9.

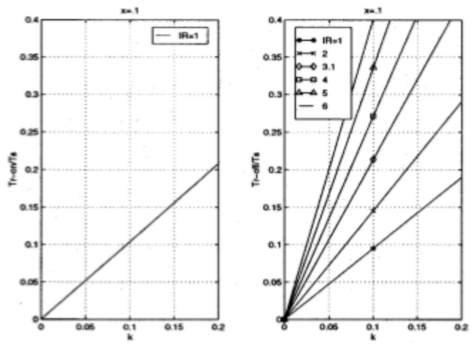


Fig. 9: The intervals of resonant turn-ON and resonant turn-OFF [16]

The value of snubber inductor, snubber capacitor, and buffer capacitor can be calculated by using the expressions as follows:

$$L_s = \frac{kT_s V_{out}}{2\pi I_{\max}} \tag{23}$$

$$C_s = \frac{kT_s I_{\max}}{2\pi V_{out}} \tag{24}$$

$$C_b = \frac{C_r}{0.1} \tag{25}$$

5. Results and Analyses

In order to verify the validity of the DC-DC boost converter circuit with ZVS QR or passive lossless snubber, the simulation results are obtained. Table 1 shows the parameters of DC-DC boost converter for hard-switching technique. Meanwhile, Table 2 and Table 3 show the parameters use in ZVS QR circuit and passive lossless snubber circuit, respectively.

Table 1: Parameters of DC-DC boost converter in hard-switching

Parameter	Value
Output power, P_{out} (W)	500
Output voltage, V_{out} (V)	200
Duty cycle, D	0.5
Switching frequency, f_{sw} (kHz)	50
Boost inductor, L_{boost} (H)	1×10^{-3}
Output capacitor, C_{out} (F)	470×10^{-6}

Table 2: Parameters of ZVS QR circuit

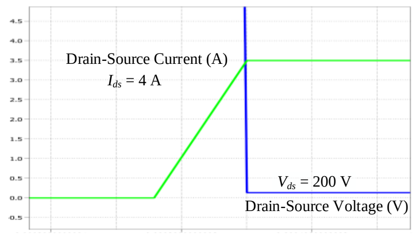
Parameter	Value
Switching frequency, f_{sw} (kHz)	50
Resonant inductor, L_r (μH)	88
Resonant capacitor, C_r (nF)	35

Table 3: Parameters of passive lossless snubber circuit

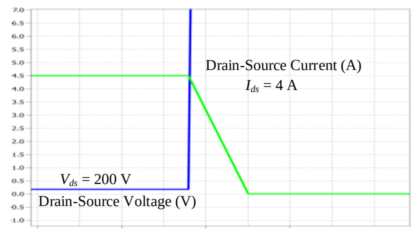
Parameter	Value
Switching frequency, f_{sw} (kHz)	50
Snubber inductor, L_s (μH)	13
Snubber capacitor, C_s (nF)	8
Buffer capacitor, C_b (nF)	80

5.1. Analysis of DC-DC boost converter in hard-switching technique

The analysis of DC-DC boost converter in hard-switching is obtained in order to verify that the operation of turn-ON and turn-OFF at the switching device is lossy. Based on Table 1, the simulation results are obtained by using PLECS simulator. The switching frequency of 50 kHz is selected in the simulation works. In order to analyse the losses in semiconductor device, IRFP4229 of MOSFET model and RFUH10TF6SFHC9 of fast diode model is refer. The switching loss and conduction loss is considered in semiconductor device for MOSFET and diode. Fig. 10 shows the simulation result of DC-DC boost converter in hard-switching where the overlapping between drain source current I_{ds} and drain source voltage V_{ds} during turn-ON and turn-OFF occurred.



(a) During turn-ON condition



(b) During turn-OFF condition

Fig. 10: Hard-switching in switching device S

By using equation (5), the switching loss of DC-DC boost converter in hard-switching condition can be calculated. Meanwhile, the conduction loss at MOSFET and diode can be calculated by using equation (6) and (7), respectively. The summation of total semiconductor losses in MOSFET and diode by using those equations is 3.37 W. In order to calculate the efficiency of the converter, this paper only consider the losses in semiconductor devices in this analysis.

5.2. Analysis of ZVS QR circuit in DC-DC boost converter

Based on Table 2, the parameters of resonant inductor and resonant capacitor is calculate based on the principle that has been explained in the previous section. The simulation results of drain source voltage and drain source current has been obtained in order to confirm the effective of soft-switching technique by using ZVS QR circuit. Figure 11 shows that the condition of drain source voltage and drain source current where the drain source voltage is approximately 350 V, meanwhile, the drain source current is 3.7 A. It can be observed that the voltage on switching device is high if compared in hard-switching technique. This is due to the reshaping of drain source voltage to realize the soft-switching condition. Basically, the energy of drain source voltage is similar in the hard-switching technique, however, the maximum of the peak voltage will differ, where the maximum of the peak voltage in ZVS QR is increasing.

Figure 12 shows that, there are no overlapping between drain source voltage and drain source current which do not produce any losses in switching device. Figure 12(a) shows during turn-ON condition, the ZVS condition is achieved where the drain source voltage is fall to zero before the drain source current rise. Figure 12(b) shows that during turn-OFF condition, soft turn-OFF is also achieved where the switching loss during turn-ON and turn-OFF is totally eliminated in DC-DC boost converter.

Figure 13 shows the simulation result of output voltage V_{out}, input voltage V_{in} and the current ripple at the boost inductor ΔI_L. By implementing ZVS QR in DC-DC boost converter, the degradation of output voltage is occurred where the output voltage of the converter is 183 V with the duty cycle of 0.5. This maybe due to the energy required in the circuit to charge and discharge the resonant components to realize the soft-switching condition. The degradation of output voltage in DC-DC boost converter is almost 13 V. The current ripple of boost inductor shows the stagnant condition where it may occur due to the resonant components in DC-DC boost converter circuit.

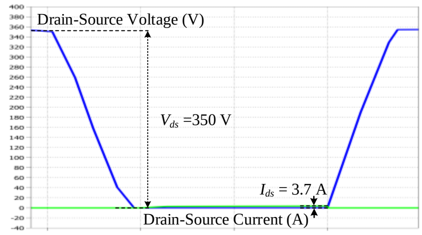
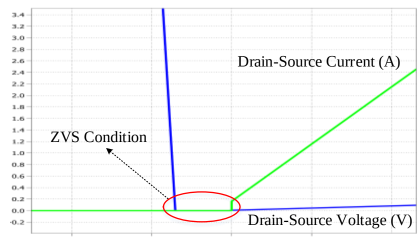
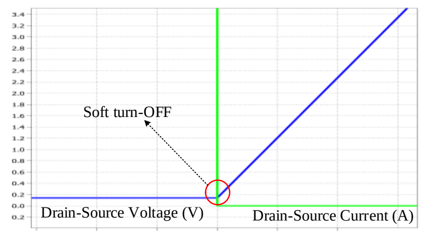


Fig. 11: Condition of V_{ds} and I_{ds} at switching device S



(a) During turn-ON condition



(b) During turn-OFF condition

Fig. 12: Soft-switching in switching device S

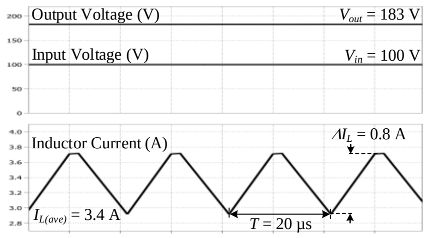


Fig. 13: Output voltage V_{out}, input voltage V_{in} and current ripple of boost inductor ΔI_L for DC-DC boost converter with ZVS QR implementation

5.3. Analysis of passive lossless snubber in DC-DC boost converter

Referring to Table 3, the parameters are used in order to achieve soft-switching in DC-DC boost converter. These parameters are calculated by using equation from (17) to (25). The natural balancing circuit is calculated for 50 kHz switching frequency. The value of snubber inductor must be much smaller if compared to the boost inductor. Meanwhile, the snubber capacitor is 1/10 from the buffer capacitor. Figure 14 shows the condition of drain source voltage and drain source current at switching device by implementing passive lossless snubber at DC-DC boost converter circuit. From the result, it shows that the drain source voltage and drain source current is almost similar like in hard-switching technique. Principally, this passive lossless snubber circuit has an ability of minimum voltage stress on switching device. This can be seen when the voltage on switching device is similar with the output voltage 200 V.
Figure 15(a) and Figure 15(b) show that the soft turn-ON and soft turn-OFF is achieved, respectively. There is no overlapping between drain source voltage and drain source current. Thus, the switching loss in the switching device can be neglected due to the elimination of switching loss during turn-ON and turn-OFF conditions. However, in certain switching frequency, the switching loss during turn-ON and turn-OFF is not totally eliminate. But, the switching loss still reduce greatly if compared to hard-switching.

Figure 16 shows the output voltage, input voltage and boost inductor current ripple of DC-DC boost converter with passive lossless snubber implementation. From the result, it shows that there is no degradation of output voltage occurred in the converter. The output voltage of the converter with the duty cycle 0.5 is 200 V. The current ripple of boost inductor also shows that there are no any stagnant condition shows in the ripple.

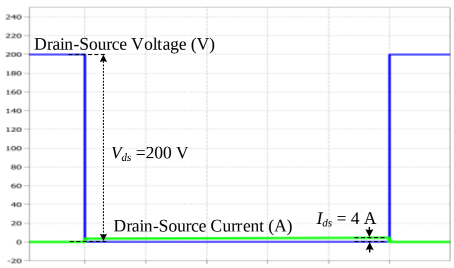
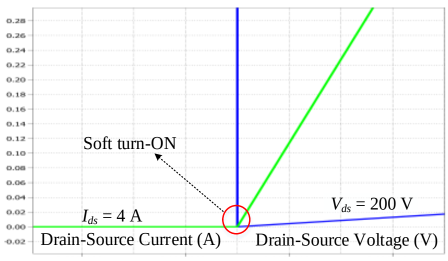
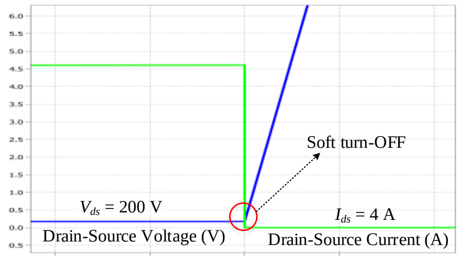


Fig. 14: Condition of V_{ds} and I_{ds} at switching device S



(a) During turn-ON condition



(b) During turn-OFF condition

Fig. 15: Soft-switching in switching device S

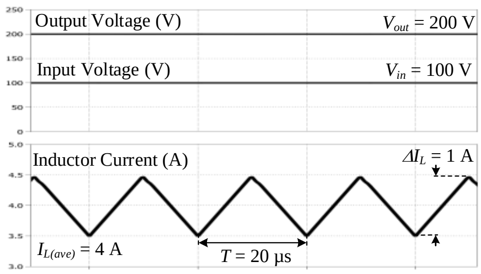


Fig. 16: Output voltage V_{out}, input voltage V_{in} and current ripple of boost inductor ΔI_L for DC-DC boost converter with passive lossless snubber

5.4. Losses and efficiency comparison

Table 4 shows the losses of semiconductor which contributed by semiconductor devices. The conduction loss is divided to conduction loss in MOSFET $P_{cond(m)}$ and conduction loss in diode $P_{cond(d)}$. The total power losses P_{loss} in semiconductor device is calculated in terms of power. The analysis shows that the total power losses of DC-DC boost converter in hard-switching technique is 6.43 W. Meanwhile, the total power losses in both soft-switching technique is similar which is 3.06 W. This is due to the elimination of switching loss in both soft-switching technique. By considering the degradation of output voltage and semiconductor losses, the efficiency of converter in soft-switching – ZVS QR and soft-switching – passive lossless snubber is 99.24 % and 82.99 %, respectively. By considering high switching frequency, the different of converter efficiency is larger as compared to low switching frequency.

Table 4: Losses analysis in hard-switching and soft-switching

Switching Technique	Switching Loss, P_{sw} (W)	Conduction Loss		Total Power Losses, P_{loss}, (W)
		$P_{cond(m)}$ (W)	$P_{cond(d)}$ (W)	
Hard-Switching	3.37	0.30	2.76	6.43
Soft-Switching - ZVS QR	Totally eliminated (0 W)	0.30	2.76	3.06
Soft-Switching - Passive Lossless Snubber		0.30	2.76	

5.5. Soft-switching technique comparison

Table 5 shows the comparison of soft-switching technique considered in this paper which are ZVS QR circuit and passive lossless snubber circuit. Both of this soft-switching circuit do not required any additional control. This is because both soft-switching techniques only required passive component and diodes in order to achieve soft-switching condition. However, the circuit configuration of passive lossless snubber circuit is moderately complex if compared to ZVS QR circuit due to the additional of snubber diodes. The degradation of output voltage in DC-DC boost converter by implementing ZVS QR circuit caused the efficiency of the converter much lower compared to DC-DC boost converter with passive lossless snubber circuit. The efficiency of converter is greatly increased by using passive lossless snubber circuit as the soft-switching technique. Thus, from the simulation results, losses analysis and comparison that has been made, it shows that passive lossless snubber circuit is more suitable use in DC-DC boost converter circuit as compared to the ZVS QR circuit.

Table 5: Comparison of soft-switching technique

Characteristics	ZVS QR Circuit	Passive Lossless Snubber Circuit
No. of component	Two	Six
Control requirement	No	No
Reliability	Yes	Yes
Energy loss	Yes	No
Circuit configuration	Simple	Moderate
Efficiency	82.99 %	99.24 %

6. Conclusion

As the conclusion, the authors have discussed and compared the efficiency soft-switching of ZVS QR and passive lossless snubber. The losses at semiconductor devices, which are switching loss and conduction loss, are considered. On the other hand, the degradation of output voltage of DC-DC boost converter also taken into consideration. In simulation works, the switching loss issue is rectified by applying soft-switching, where it has been realized by using ZVS QR circuit and passive lossless snubber circuit. The additional circuit of soft-switching may reduce the losses of converter at high switching frequency. Due to high switching frequency, the volume of passive components can be reduced as well. From the analysis and comparison done in this paper, passive lossless snubber circuit has significant benefit in DC-DC boost converter circuit if compared to the ZVS QR circuit. This is due to the reliability and configuration circuit of passive lossless snubber circuit for EV application.

Acknowledgement

The authors would like to express their appreciation to the Universiti Tun Hussein Onn Malaysia. This research is funded by the Universiti Tun Hussein Onn Malaysia under Tier 1 Research Grant (Vot U858), GPPS Research Grant (Vot U951), and Research Fund, UTHM.

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