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Research Article

Soft Switching for MOSFET and IGBT-Based Hybrid DC-DC Boost Converter

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Abstract: In this study, the active soft switching (SS) methods were proposed for the MOSFET and IGBT-based hybrid DC-DC boost converter with high voltage gain. The zero-voltage transition (ZVT) and the zero-current transition (ZCT) active SS methods were applied to the hybrid DC-DC boost converter with MOSFET and IGBT main switches, respectively. Thus, the hard switching (HS) power losses of MOSFET and IGBT-based hybrid DC-DC boost converter was reduced. The MOSFET and IGBT-based hybrid DC-DC boost converter with variable loads was simulated in OrCAD-PSpice environment for SS methods (ZVT and ZCT) and HS. The simulation results show that SS methods increased the efficiency of the hybrid DC-DC boost converter, nearly 1%.

MOSFET ve IGBT Tabanlı Hibrit DC-DC Boost Dönüştürücü için Yumuşak Anahtarlama

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Anahtar Kelimeler
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Öz: Bu çalışmada, yüksek voltaj kazancına sahip MOSFET ve IGBT tabanlı hibrit DC-DC yükseltici dönüştürücü için aktif yumuşak anahtarlama yöntemleri önerilmiştir. MOSFET ve IGBT ana anahtarlı hibrit DC-DC yükseltici dönüştürücüye sırasıyla sıfır voltaj geçişli ve sıfır akım geçişli aktif yumuşak anahtarlama yöntemleri uygulandı. Böylece MOSFET ve IGBT tabanlı hibrit DC-DC yükseltici dönüştürücünün sert anahtarlama kaynaklı güç kayıpları azaltılmıştır. Değişken yüklere sahip MOSFET ve IGBT tabanlı hibrit DC-DC yükselten dönüştürücü, yumuşak anahtarlama yöntemleri ve sert anahtarlama için OrCAD-PSpice ortamında benzetim çalışmaları yapılmıştır. Benzetim çalışmalarından elde edilen sonuçlar, yumuşak anahtarlama yöntemlerinin hibrit DC-DC yükseltici dönüştürücünün verimini %1 kadar arttırdığını göstermektedir.

1. Introduction

DC-DC converters have an essential importance in many fields such as sustainable and renewable energy systems, mobile electrical devices, communication systems, hybrid electric power systems, electric vehicles, and uninterruptible power supplies (Hai-Bo & Kim, 2021). The DC-DC converters are used to obtain the desired output voltage in the cases given in (Guo et al., 2015; Theunisse et al., 2015; Yang et al., 2017). There are two types of DC-DC converters such as isolated and non-isolated for different applications (Alassi et al., 2017). The different structures of isolated DC-DC converters have been proposed in many scientific publications in the power electronics area (Gopi & Saravanakumar, 2014). The non-isolated DC-DC converter is very attractive due to its low cost, easy modelling, small size, simple design application and manufacturing (Forouzesh et al., 2017).

The applications with non-isolated DC-DC converters can be achieved with higher efficiency and power density by smaller step rates (Biela et al., 2009). The DC-DC boost converters in continuous conduction mode (CCM) have become very common, especially in applications where the input voltage should be greater than the output voltage (Kobaku et al., 2021).

In particular, the low-level DC voltage value provided by renewable energy sources can be used for on-grid or off-grid systems by stepping up with non-isolated DC-DC boost converters. The researchers have focused on the non-isolated DC-DC converters with high efficiency and conversation ratio. In applications requiring high voltage gain, where the conventional DC-DC boost converter is insufficient, Switching Capacitor circuits that are applied with a switch and capacitor can be a solution. Another solution is the DC-DC boost converters obtained by adding the diodes and capacitors to the conventional boost converters (Rosas-Caro et al., 2018).

The high power density and efficiency can be achieved for converters by reducing the power losses as much as possible. The main cause of power losses is switching, generally (Pavlovsky et al., 2014). HS converters are often switched at high frequencies for high power densities and fast transient responses (Eskandari et al., 2020); but operating at high frequencies increases switching losses and electromagnetic interference (EMI) noise (Genc & Koc, 2017). There are two SS methods such as passive and active. The passive SS methods consist of diodes, capacitors and inductors and cause high current and voltage stresses on the main switch. The active SS methods consist of an auxiliary switch added to the circuit elements used for the passive SS methods (Dao & Lee, 2020).

The main purpose of this study is to make SS for MOSFET and IGBT-based hybrid DC-DC boost converter with ZVT and ZCT, respectively. The total efficiency of MOSFET and IGBT-based hybrid DC-DC boost converter was increased by reducing switching losses with ZVT and ZCT. The MOSFET and IGBT-based hybrid DC-DC boost converter with SS and HS was simulated in OrCAD-PSpice environment for 200W.

2. Material and Methods

2.1. Hybrid DC-DC boost converter

It is possible to operate the conventional DC-DC boost converter for high voltage gain with high duty cycle (d). However, high d levels cause undesired errors, so d should be limited (Wai & Duan, 2005). The hybrid DC-DC boost converter is a superb candidate. Because it can reach desired high voltage gain via smaller d (Padmanaban et al., 2015). The hybrid DC-DC boost converter is operated by only one switch (Lange et al., 2014). The hybrid DC-DC boost converter, operation modes and waveforms are given in Figure1.

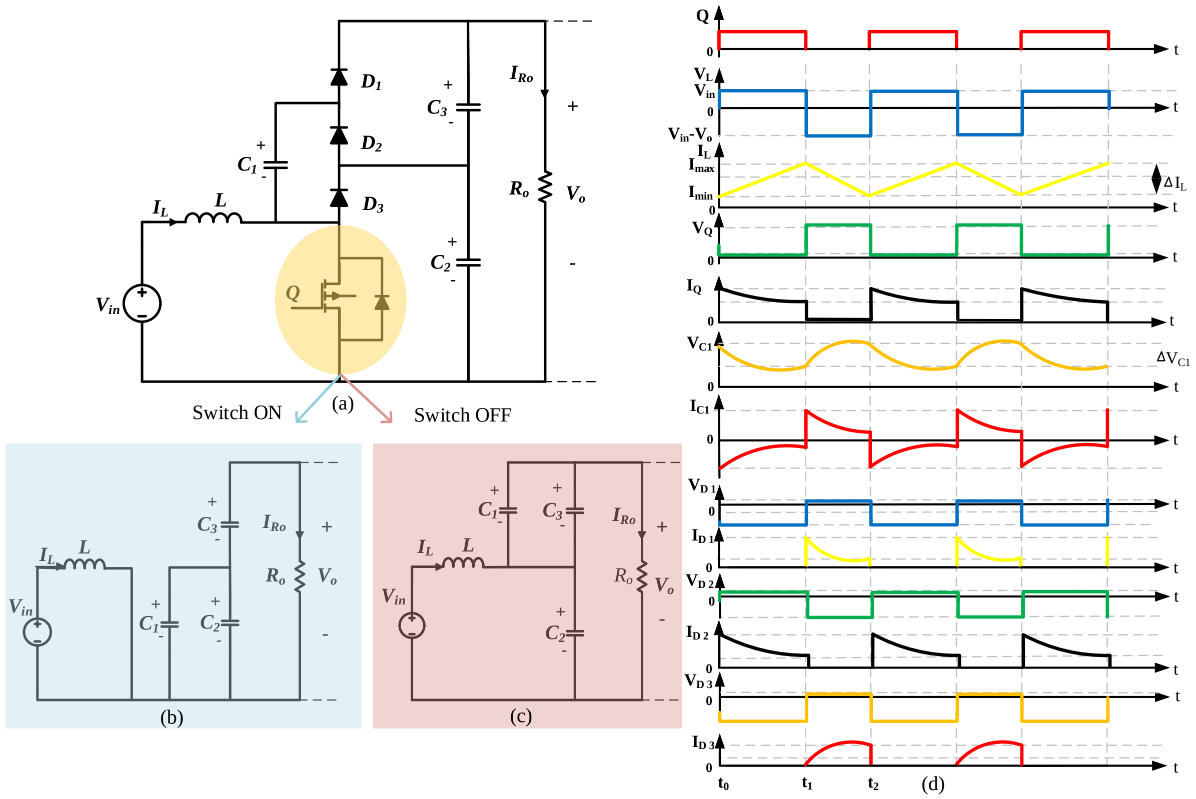

Figure 1. (a) Hybrid DC-DC boost converter, (b) when switch Q is on (c) when switch Q is off, and (d) the waveforms.

The relationship between input and output voltages for the hybrid DC-DC boost converter was given in Equation 1.

$$V_o = 2\frac{V_{in}}{(1-d)} \tag{1}$$

The critical levels of components for the hybrid DC-DC boost converter were determined according to the information given in (Rashid, 2004). The components of the hybrid DC-DC boost converter are given in Table 1.

Table 1. The components of the hybrid DC-DC boost converter.

Parameters for the hybrid DC-DC boost converter	Values
Output power (P_o)	200 W
Input voltage (V_{in})	40-100 V
Output voltage (V_o)	200 V
Switching frequency (f_s)	50 kHz
Inductor (L)	500 mH
Capacitors ($C1$, $C2$, $C3$)	25, 470, 470 µF
Switch (Q)(MOSFET/IGBT)	IRFP460/ IXGN24N60C4D1
Diodes ($D1$, $D2$, $D3$)	DSEP8-12A

2.2. ZVT and ZCT for hybrid DC-DC boost converter

The main losses of the hybrid DC-DC boost converter are related to the main switch (Q) states. These losses reduce the total efficiency of the hybrid DC-DC boost converter. The hybrid DC-DC boost converter consists of the main switch (Q), main inductor (L), $D1$, $D2$, $D3$, $C1$, $C2$, $C3$, and R_o as shown in Figure 1(a). The auxiliary circuit for ZVT and ZCT consists of a resonance inductor

(L_a), capacitors (C_a, C_s), two auxiliary diodes (D_{a1}, D_{a2}) and a switch (Q_a). The proposed ZVT SS method was preferred for MOSFET-based hybrid DC-DC converter because of the parasitic capacitance that occur on the MOSFET when the MOSFET turns on (Yao & Xiao, 2013). Also, the proposed ZCT SS method was used for the IGBT-based converter due to the tail currents that occur when the IGBT turns off (Wang et al., 2014).

2.3. MOSFET-based hybrid DC-DC boost converter with ZVT

While the main switch of the MOSFET-based hybrid DC-DC converter is turning on, it is desired that the voltage on the main switch is zero during the current transition. It can be achieved by utilizing ZVT. The components of the hybrid DC-DC boost converter were summarized in Table 1. The components of the auxiliary circuit for MOSFET-based hybrid DC-DC converter were given in Table 2. The MOSFET-based hybrid DC-DC converter with the auxiliary circuit for ZVT is given in Figure 2. The power losses of main switch (MOSFET) were reduced with ZVT SS method.

Table 2. The components of the auxiliary circuit for the MOSFET-based hybrid DC-DC converter

Parameters for the auxiliary	Values
Auxiliary switch (Q_a)	IRFP460
Auxiliary switching frequency (f_{sa})	50 kHz
Auxiliary inductor (L_s)	4 µH
Auxiliary diodes (D_{a1}, D_{a2})	DSEP8-12A
Auxiliary capacitors (C_s, C_a)	1.4, 6 nF

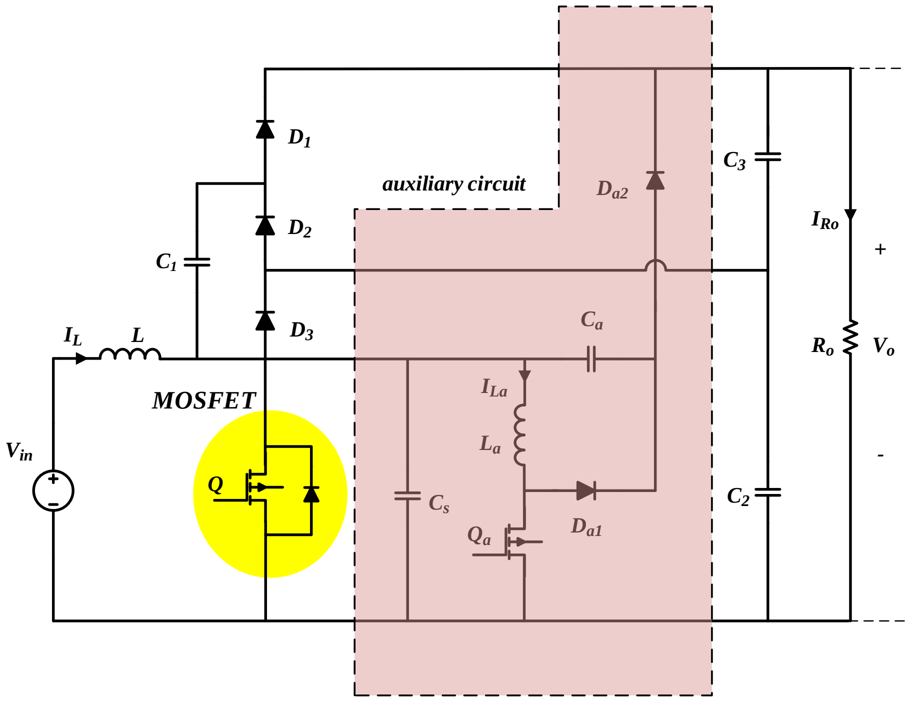

Figure 2. The MOSFET-based hybrid DC-DC converter with the auxiliary circuit for ZVT.

2.4. IGBT-based hybrid DC-DC boost converter with ZCT

While the main switch of IGBT-based hybrid DC-DC converter is turning off, it is desired that the current is zero during voltage transition and it can be done via ZCT. The components of the hybrid DC-DC boost converter were summarized in Table 1. The components of the auxiliary circuit for IGBT-based hybrid DC-DC converter were given Table 3.

Table 3. The components of the auxiliary circuit for IGBT-based hybrid DC-DC converter

Parameters for the auxiliary	Values
Auxiliary switch (Q_a)	IRFP460
Auxiliary switching frequency (f_{sa})	50 kHz
Auxiliary inductor (L_s)	4 µH
Auxiliary diodes (D_{a1}, D_{a2})	DSEP8-12A
Auxiliary capacitors (C_s, C_a)	1.4, 6 nF

The IGBT-based hybrid DC-DC converter with the auxiliary circuit for ZCT is given in Figure 3. The power losses of main switch (IGBT) were reduced with ZCT SS method.

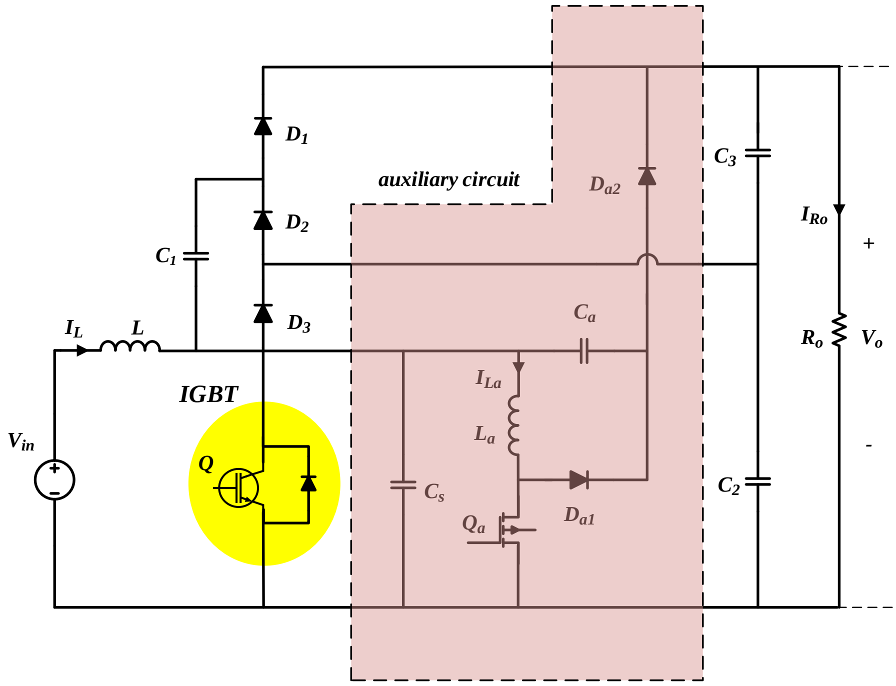

Figure 3. The IGBT-based hybrid DC-DC converter with the auxiliary circuit for ZCT.

3. Results

The MOSFET-based hybrid DC-DC boost converter with ZVT and the IGBT-based hybrid DC-DC boost converter with ZCT were operated for variable loads in OrCAD-PSpice environment.

Table 4. The efficiency of MOSFET-based hybrid DC-DC boost converter

P_o	HS	ZVT
100 W	%93,84	%94,73
200 W	%96,05	%96,97
300 W	%97,18	%98,11

Table 5. The efficiency of IGBT-based hybrid DC-DC boost converter

P_o	HS	ZCT
100 W	%93,71	%94,68
200 W	%95,43	%96,39
300 W	%96,37	%97,08

The efficiency of MOSFET and IGBT-based hybrid DC-DC boost converter for HS and SS under variable loads is given in Table 4, Table 5 and Figure 4. The simulation results of MOSFET-based hybrid DC-DC boost converter with ZVT and IGBT-based hybrid DC-DC boost converter with ZCT are given in this section.

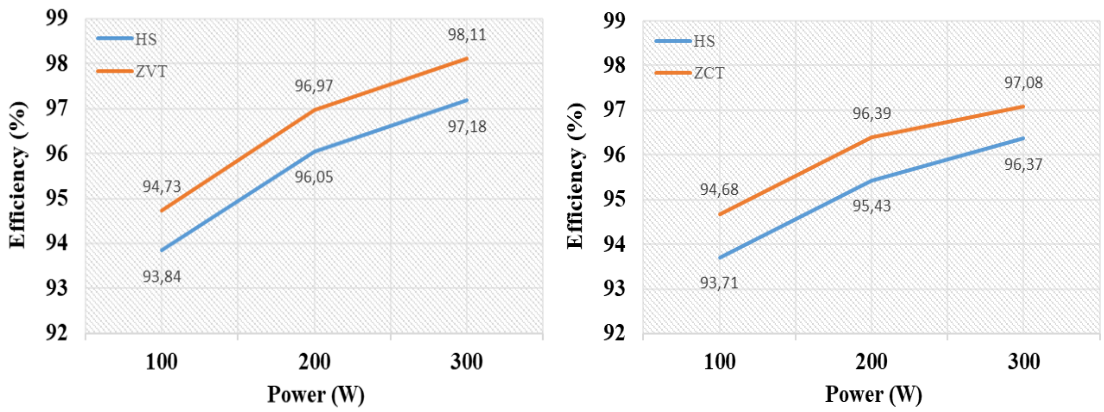

Figure 4. The efficiency of MOSFET (ZVT) and IGBT (ZCT)-based hybrid DC-DC boost converter for HS and SS under variable load.

3.1. Simulation results for MOSFET-based hybrid DC-DC boost converter with ZVT

The MOSFET-based hybrid DC-DC boost converter that operated for 200 W was simulated to compare HS and SS (ZVT). The simulation results of proposed system were given in Figure 5.

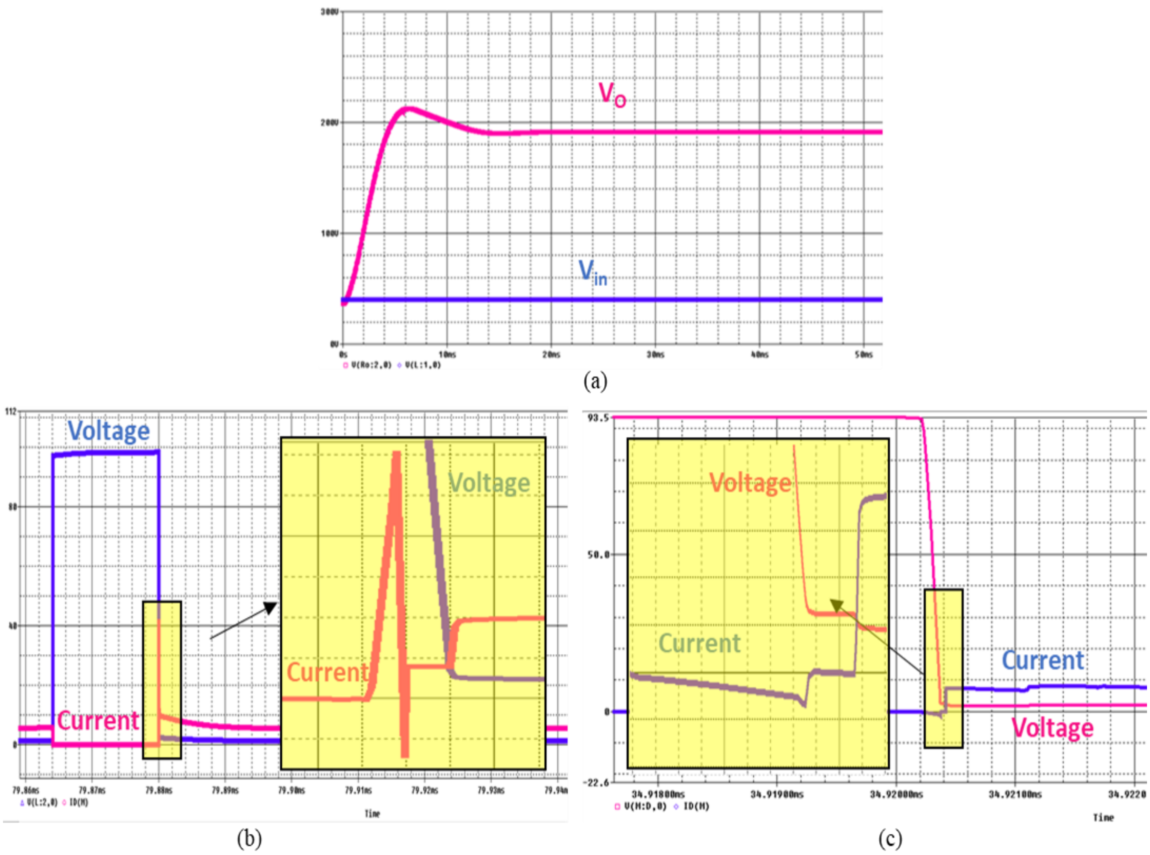

Figure 5. The simulation results of MOSFET-based hybrid DC-DC converter for (a) V_{in}-V_o, (b) HS and (c) SS (ZVT).

The input and output voltage of the proposed system were given in Figure 5(a). While the main switch (MOSFET) was turning off, the power losses occurred due to the parasitic capacitance of the MOSFET. As can be seen in Figure 5(b), the MOSFET power losses was quite high for the MOSFET-based hybrid DC-DC converter with HS. The power losses were reduced by applying ZVT SS method to the MOSFET-based hybrid DC-DC converter (Figure 5(c)). Thus, the efficiency of the MOSFET-based hybrid DC-DC converter was increased.

3.2. Simulation results for IGBT-based hybrid DC-DC boost converter with ZCT

The IGBT-based hybrid DC-DC boost converter that operated for 200 W was simulated to compare HS and SS (ZCT). The simulation results of proposed system were given in Figure 6.

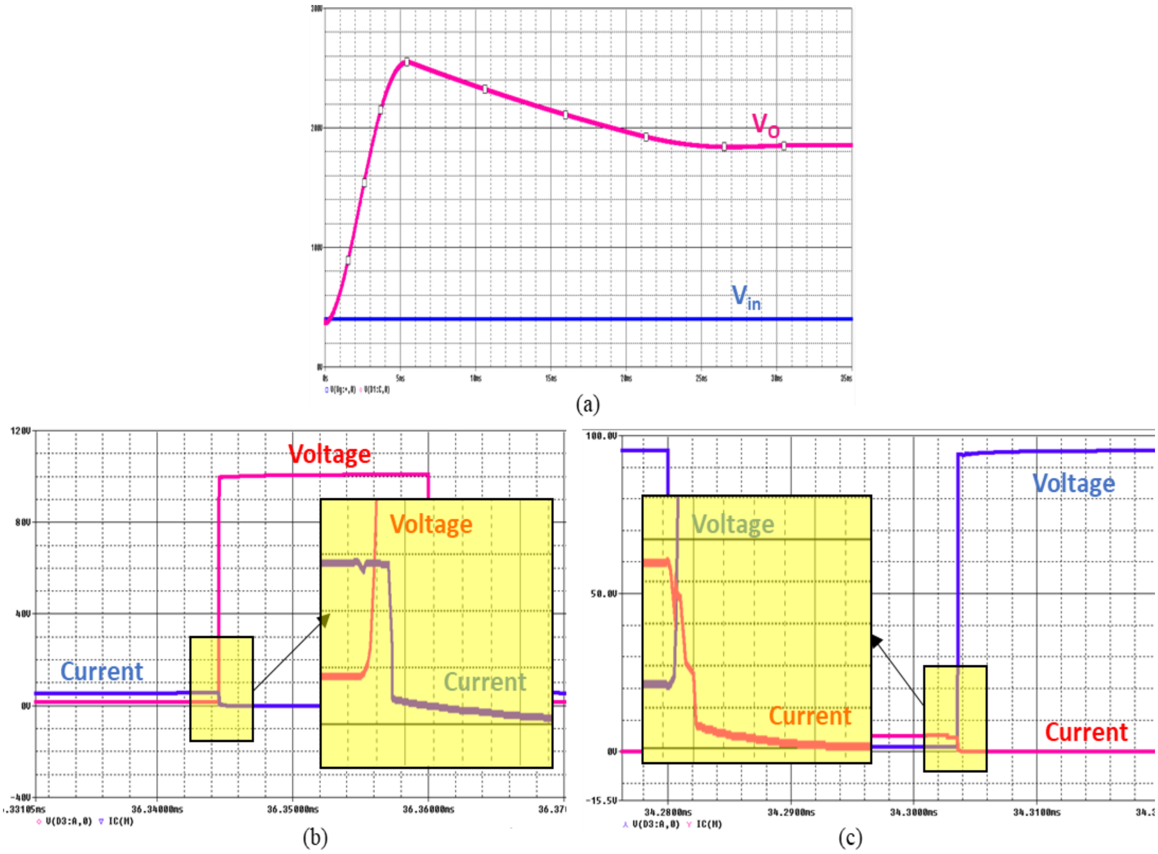

Figure 6. The simulation results of IGBT-based hybrid DC-DC converter for (a)V_{in}-V_o, (b) HS and (c) ZCT.

The input and output voltage of the proposed system were given in Figure 6(a). The IGBT-based hybrid DC-DC converter was operated for HS, the tail current on the main switch (IGBT) was given in Figure 6(b). The tail current of IGBT was considerably shortened as in Figure 6(c) thanks to the ZCT SS method. Thus, the power losses on IGBT, while it was turning off were decreased and the efficiency of the IGBT-based hybrid DC-DC converter was increased.

4. Discussion and Conclusion

In this study, a hybrid DC-DC boost converter with SS was presented for different main switches (MOSFET/IGBT). The MOSFET and IGBT-based hybrid DC-DC boost converter was simulated for 200 W in OrCAD-PSpice environment with ZVT and ZCT, respectively. The auxiliary circuit was used to operate the MOSFET-based hybrid DC-DC boost converter with ZVT and the IGBT-based hybrid DC-DC boost converter with ZCT. The components of the auxiliary circuit used for the SS were determined separately for the MOSFET and IGBT-based hybrid DC-DC boost converter. In the MOSFET-based hybrid DC-DC boost converter, the power losses on the main switch occur while the main switch turns on. The power losses on the main switch for the IGBT-based hybrid DC-DC boost converter occur while the main switch turns off. The total efficiency of the hybrid DC-DC boost converter increased about 1% via SS methods for variable loads. In the future, ZVT and ZCT can be applied together to both the MOSFET and IGBT-based hybrid DC-DC boost converter with the auxiliary circuit during a switching period.

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