Loss Analysis of Half Bridge DC-DC Converters in High-Current and Low-Voltage Applications

A. Faruk Bakan, İsmail Aksoy, Nihan Altintaş

Abstract—In this paper, half bridge DC-DC converters with transformer isolation presented in the literature are analyzed for high-current and low-voltage applications under the same operation conditions, and compared in terms of losses and efficiency. The conventional and improved half-bridge DC-DC converters are simulated, and current and voltage waveforms are obtained for input voltage V_{dc}=500V, output current I_O=450A, output voltage V_O=38V and switching frequency f_S=20kHz. IGBTs are used as power semiconductor switches. The power losses of the semiconductor devices are calculated from current and voltage waveforms. From simulation results, it is seen that the capacitor switched half bridge converter has the best efficiency value, and can be preferred at high power and high frequency applications.

Keywords—Isolated half bridge DC-DC converter, high-current low-voltage applications, soft switching, high efficiency.

I. INTRODUCTION

HALF BRIDGE (HB) DC-DC converters have been widely used in power electronics applications because of their simple structure and ease of control. The semiconductor switches of the conventional isolated half bridge DC-DC converter turns off with hard switching. The switching frequency can not be increased because of the turn off losses and the oscillation between parasitic capacitance of the power swithes and the leakage inductance of the transformer [1-10].

In the literature, additional auxiliary circuits are developed to solve the problems of the conventional half bridge converter. The main purpose of these circuits is to decrease the turn off losses of the semiconductor switches and parasitic oscillations.

In this paper, half bridge DC-DC converters with transformer isolation presented in the literature are analyzed under the same operation conditions, and compared in terms of losses and efficiency. The conventional converter [1-2] and the improved converters [3-10] are simulated by PROTEUS program for input voltage V_{dc}=500 V, output current I_O=450 A, output voltage V_O=38V, and operating frequency f_S=20 kHz.

A. Faruk Bakan is with the Yildiz Technical University Electrical Engineering Department, Esenler, 34220 Turkey (phone: 90-212-3835815; fax: 90-212-3835858; e-mail: fbakan@yildiz.edu.tr).

İsmail Aksoy is with the Yildiz Technical University Electrical Engineering Department, Esenler, 34220 Turkey (phone: 90-212-3835816; fax: 90-212-3835858; e-mail: iaksoy@yildiz.edu.tr).

Nihan Altintaş is with the Yildiz Technical University Electrical Engineering Department, Esenler, 34220 Turkey (phone: 90-212-3835845; fax: 90-212-3835858; e-mail: naltin@yildiz.edu.tr).

The power losses of the semiconductor devices and efficiency values are calculated from current and voltage waveforms. The advantages/disadvantages of the converters are discussed comparatively.

II. ANALYSIS OF HALF BRIDGE DC-DC CONVERTER TOPOLOGIES

At high power and high voltage applications IGBTs are preferred as power semiconductor switches. 1200V/200A IGBT is used in the simulations. The IGBT has 20 mj turn off loss at nominal current. The parameters of the high frequency power transformer are given in Table I. The magnetic coupling of the transformer is accepted ideal (M=1), and the leakage inductance is represented with a series inductor.

TABLE I
HIGH FREQUENCY POWER TRANSFORMER PARAMETERS

Turns ratio	3:1
Primary inductance	450 µH
Secondary inductance	100 µH
Coupling (M)	1
Primary resistance	5 mΩ
Secondary resistance	1 mΩ

A. HB Topology 1

The conventional HB converter [1-2] is given in Fig. 1 and the simulation results are given in Fig. 2. L_K is selected as 3µH. In practice, the minimum value of leakage inductance of the transformer can be realized around 1-2 µH.
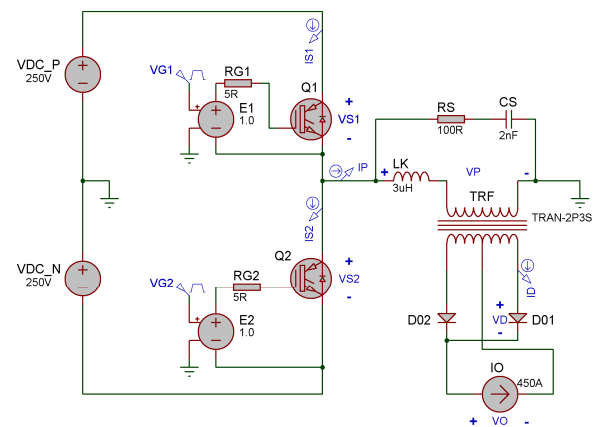

Fig. 1 The conventional HB circuit

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In HB converter, two equal DC voltage sources are required. Q_1 and Q_2 power switches are operated symmetrically. As a result, half of the DC bus voltage is applied symmetrically across the transformer's primary winding. In order to prevent short circuit, dead time is inserted between the control signals of switches.
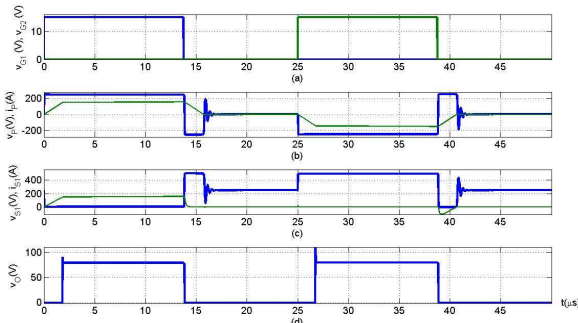

Fig. 2 Waveforms of HB topology 1

The power switches are turned on under ZCS due to the leakage inductance of the transformer, thus the turn-on losses are quite low. But the turn off process of the switches are realized under hard switching.

The control signals of the switches, the primary voltage and current of the transformer, the voltage and current of the switch Q_1, and the output voltage are shown in Fig.2(a), Fig.2(b), Fig.2(c) and Fig.2(d), respectively. From Fig.2(c), the switch is turned on under ZCS due to the leakage inductance of the transformer, and is turned off under hard switching.

B. HB Topology 2

The circuit scheme of the DC busline active snubber-assisted HB topology [3] is given in Fig.3 and the simulation results are given in Fig.4 and Fig.5.
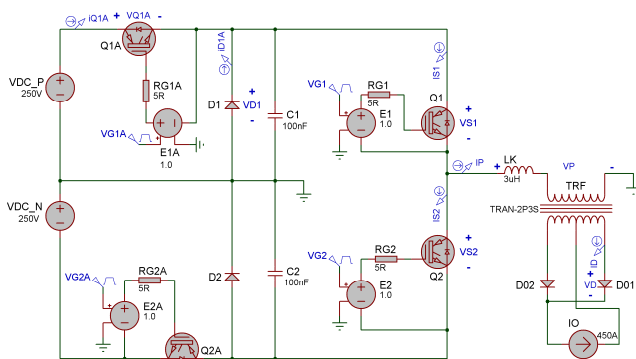

Fig. 3 DC busline active snubber-assisted HB topology

This converter is composed of conventional half bridge converter, auxiliary switches Q_{1A} and Q_{2A}, two snubber capacitors C_1, C_2, and two additional diodes D_1, D_2. The centre points of the snubber capacitors C_1, C_2 and two additional diodes D_1, D_2 are connected to half of the DC bus voltage and one of terminals of primary winding of transformers.
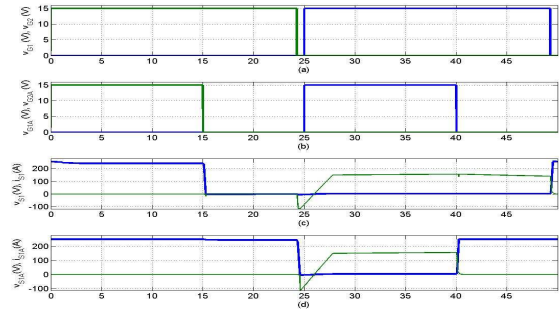

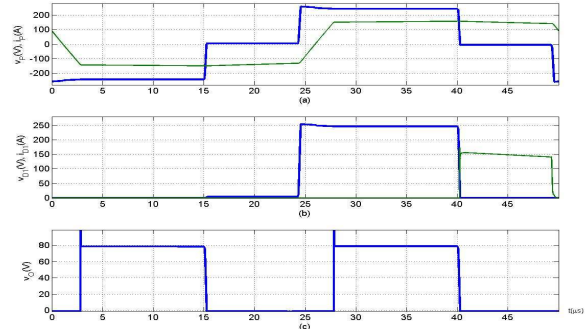Fig. 4 Waveforms of HB topology 2

Fig. 5 Waveforms of HB topology 2

In this topology, all of the power switches turn-on with ZCS and turn-off with ZVS. The turn-off switching losses can be reduced significantly.

Switches Q_1 and Q_2 are both driven by 50 % duty cycle, with a small amount of dead time. The control signals of the auxiliary switches Q_{1A} and Q_{2A} are the same as the control signals of the Q_1 and Q_2 switches in conventional HB converter. Thanks to C_1 and C_2, all of IGBTs in the circuit is turned off under ZVS. Q_1 and Q_2 switches are turned on with ZCS because of the leakage inductance of the transformer.

In this converter, at low load condition, the capacitors C_1 and C_2 is not fully charged/discharged. As a result, the capacitors directly discharged through the Q_{1A} and Q_{2A}, and there is a failure risk of IGBT. Additional power losses occur in this converter due to conduction losses of the auxiliary switches.

C. HB Topology 3

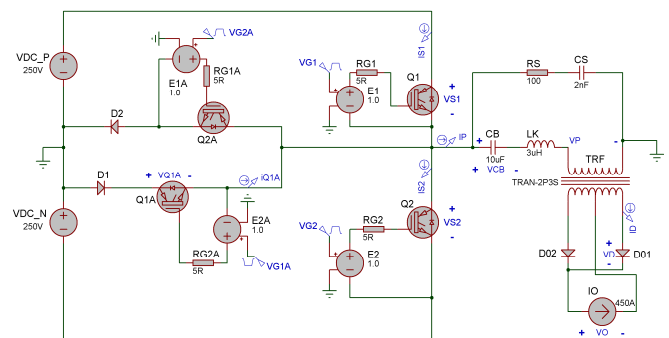Active clamp HB topology [5] is given in Fig.6, and the simulation results are given in Fig.7 and Fig.8.

Fig. 6 Active clamp HB topology

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In this topology, an active-clamp snubber is added to conventional HB converter to clamp the leakage inductance current and damp the ringing during the off-time interval of the switches. It consists of a conventional HB converter and an active clamp circuit. The active clamp contains two IGBTs with body diodes (Q_{1A} and Q_{2A}), two diodes (D_1 and D_2), and a capacitor C_B. The capacitor C_B is connected in series with the primary winding of the transformer. C_B acts as a voltage source to absorb the energy in the leakage inductance.
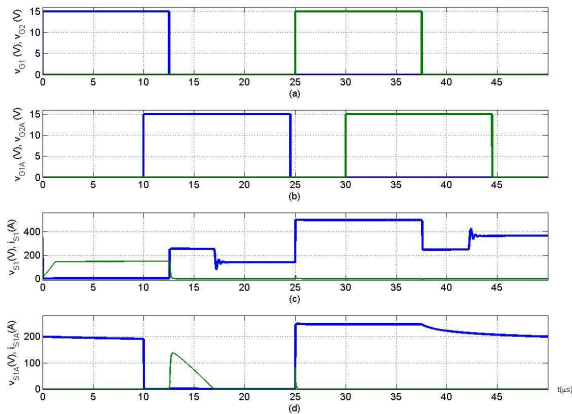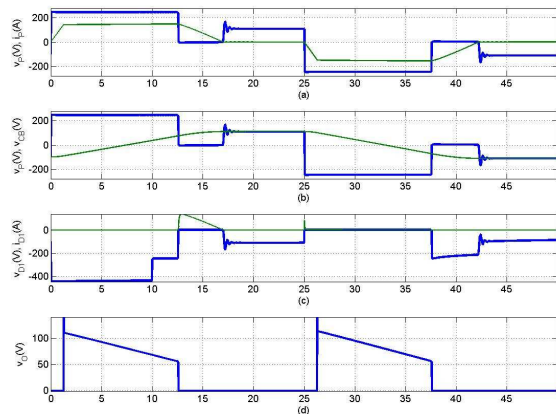

Fig. 7 Waveforms of HB topology 3

Fig. 8 Waveforms of HB topology 3

In the off-time interval of the switches, the energy which is stored in the transformer leakage inductance is transferred to capacitor C_B. The ringing is eliminated and the ringing losses are minimized. The body diodes of the main switches never conduct. As a result, the reverse recovery losses of the diodes are minimized.

Auxiliary switches are turned on and turn off with ZVZCS and the switching losses of the auxiliary switches are low. The conduction losses can be neglected because it operates in a small duration of the switching period.

The value of capacitor C_B should be small enough to fall the primary current to zero. Thus, the voltage across the capacitor is high. This voltage is reflected on the output voltage. The

selection of the capacitor value is determined according to the primary current and the leakage inductance value. In this converter, the generation of the control signals is more difficult than conventional ones. This operating mode cannot be guaranteed in transient state.

D.HB Topology 4

The switched capacitor snubber HB DC-DC converter topology [10] that uses two auxiliary switches (Q_{1A}-Q_{2A}), and two snubber capacitors (C_3-C_4) is given in Fig. 9, and the simulation results are given in Fig.10 and Fig.11.
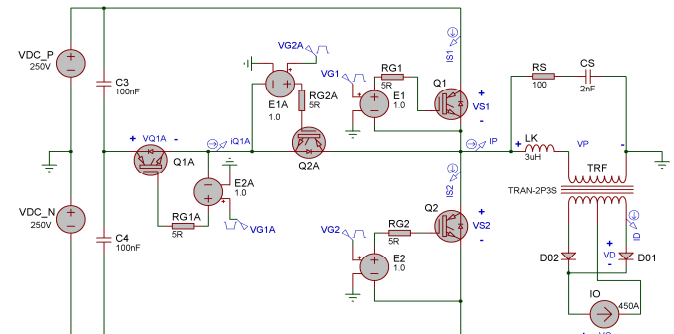

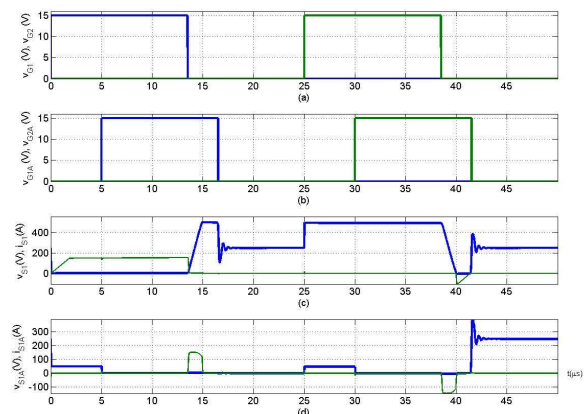Fig. 9 Capacitor switched HB DC-DC converter topology
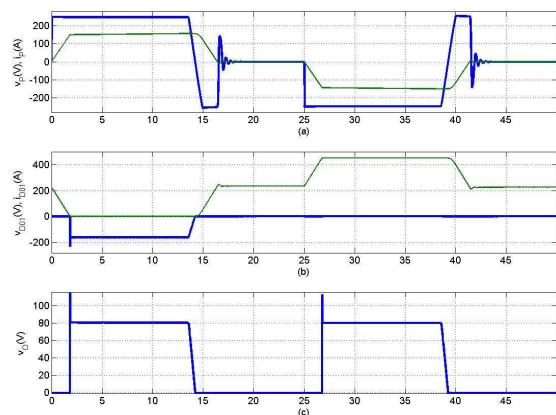

Fig. 10 Waveforms of HB topology 4

Fig. 11 Waveforms of HB topology 4

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Q_{1A} control signal is applied after Q_1 signal and removed before Q_2 signal. Q_{1A} should be removed after i_{Q1} falls to zero. Similary, Q_{2A} control signal is applied after Q_2 signal and removed before Q_1 signal. The conduction loss of the auxiliary switches is very low because they conduct current for a very short time. At the same time, the switching loss of the auxiliary switches is near zero because they turn on and turn off with soft switching.

III. COMPARISON OF HB TOPOLOGIES

The power losses and efficiency values obtained with the simulations of the HB converters under the same conditions are summarized in Table II.

TABLE II
THE POWER LOSSES AND EFFICIENCY VALUES OF THE HB CONVERTERS

	Topology 1	Topology 2	Topology 3	Topology 4
Q1 Losses	349.5 W	268.1 W	212.1 W	185.9 W
Q2 Losses	334.0 W	246.4 W	224.8 W	177.3 W
Q1A, Q2A Losses	-	331.0 W	76.2 W	71.8 W
D1A, D2A Losses	-	51.2 W	12.8 W	-
DO1, DO2 Losses	438.1 W	444.6 W	438.8 W	446.6 W
Total Losses	1121.6 W	1341.4 W	964.7 W	881.6 W
Efficiency	**93.85%**	**92.79%**	**94.56%**	**95.12%**

Topology 1: In this topology, the power switches turn on under ZCS but turn off under hard switching. For this reason, turn-off losses of the IGBTs are extremely high, and the efficiency of the converter decreases with increasing frequency. In addition, the parasitic oscillations between the parasitic capacitor and the leakage inductance cause EMI noise. To reduce parasitic oscillations RC snubber circuit is connected across the primary windings of the transformer. The leakage inductance energy is dissipated on the snubber resistance. As a result, the efficiency of the converter is decreased at high frequency.

Topology 2: In this topology, all the power switches turn on under ZCS and turn off under ZVS. Turn off losses of the main switches decrease, but additional conduction losses occur in the auxiliary switches. This converter can be operated at higher frequencies than the conventional converter. The charge/discharge of the snubber capacitors depend on the output current. Dead time must be adjusted depending on the output current, and this increases control complexity.

Topology 3: In this topology, the main power switches turn on under ZCS. Auxiliary switches turn on and turn off with ZVZCS. The switching losses of the auxiliary switches are low. In the off-time interval of the switches, the energy which is stored in the transformer leakage inductance is transferred to the capacitor C_B. The ringing is eliminated and the ringing losses are minimized. The body diodes of the switches never conduct. As a result, the reverse recovery losses of the diodes are minimized.

Topology 4: In this topology, all the power switches turn on under ZCS and turn off ZVS. Auxiliary switches turn on and turn off with soft switching. By means of the auxiliary circuit the converter can be operated at very high frequencies.

From simulations it is seen that topology 4 has the highest efficiency. The efficiency of topolgy 2 is the lowest because of additional losses. In all these topologies, power losses on the secondary rectifiers are quite high, and they may be decreased by using synchronous rectifier structure.

IV. CONCLUSIONS

In this paper, HB DC-DC converters in the literature have been examined under the same conditions and compared in terms of losses and efficiency. It is seen that the capacitor switched half bridge converter has the best efficiency value, and can be preferred at high power and high frequency applications.

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A. Faruk Bakan was born in Istanbul, Turkey, in 1972. He received the B.S. degree in electronics and communication engineering, the M.S. degree in electrical engineering, and the Ph.D. degree in electrical engineering from Yildiz Technical University, Istanbul, in 1994, 1997 and 2002, respectively.Since 2002, he has been a Assistant Professor in the Department of Electrical Engineering, Yildiz Technical University. He has authored or coauthored 14 journal and conference papers in the area of power electronics. He was also engaged in seven research projects involving power electronics. His current research interests include direct torque control, photovoltaic inverters, welding machines, and soft-switching techniques in power electronics.

Nihan Altintas was born in Balıkesir, Turkey, in 1980. She received the B.S., and M.S., degrees in electrical engineering from Yildiz Technical University, Istanbul, Turkey, in 2004 and 2007, respectively. She is a PhD student in the same department. She has authored or coauthored 5 journal and conference papers in the area of power electronics. She was also engaged in seven research projects involving power electronics.

Ismail Aksoy was born in Cologne, Germany, in 1977. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Yildiz Technical University, Istanbul, Turkey, in 1999, 2001, and 2007, respectively. From 1999 to 2008, he was a Research Assistant in the Department of Electrical Engineering, Yildiz Technical University, where he has been a Assistant Professor in the Department of Electrical Engineering since 2008. He has authored or coauthored more than 10 journal and conference papers in the area of power electronics. He was also engaged in three research projects involving power electronics. His current research interests include power-factor correction, switching power supplies, high-frequency power conversion, and active and passive snubber cells in power electronics.