IJournals: International Journal of Software & Hardware Research in Engineering
ISSN-2347-4890
Volume 3 Issue 12 December, 2015

Full-Bridge Boost Converter with a Flyback Snubber using ZVS technique

E.Immanuvelbright[1], L.Vijay Anand[2], S.Vijayanand[3]

[1]Assistant Professor, Erode Sengunthar Engineering College, Thudupathi.

[2]Assistant Professor, Erode Sengunthar Engineering College, Thudupathi.

[3]Assistant Professor, Erode Sengunthar Engineering College, Thudupathi.

[1]bright.eib@gmail.com

[2]vijay.21a@gmail.com

[3]svijayanandme@gmail.com

Abstract— ***An isolated bidirectional full-bridge boost converter with high conversion ratio, high output power, and soft start-up capability is proposed in this paper. The use of a capacitor, a diode, and a flyback converter can clamp the voltage spike caused by the current difference between the current-fed inductor and leakage inductance of the isolation transformer, and can reduce the current flowing through the active switches at the current-fed side. Operational principle of the proposed converter is first described, and then, the design equation is derived.***

Keywords— **Flyback converter, isolated full-bridge bidirectional converter, soft start-up.**

I. INTRODUCTION

In Renewable dc-supply systems, batteries are usually required to back-up power for electronic equipment. Their voltage levels are typically much lower than the dc-bus voltage. Bidirectional converters for charging/discharging the batteries are therefore required. For high-power applications, bridge-type bidirectional converters have become an important research topic. For raising power level, a dual full-bridge configuration and its low side and high side are typically configured with boost-type and buck-type topologies, respectively. The major concerns of these studies include reducing switching loss, reducing voltage and current stresses, and reducing conduction loss due to circulation current. A more severe issue is due to leakage inductance of the isolation transformer, which will result in high voltage spike during switching transition. Additionally, the current freewheeling due to the leakage inductance will increase conduction loss and reduce effective duty cycle. The leakage inductance to raise its current level up to that of the current-fed inductor, which can reduce their current difference and, in turn, reduce voltage spike. However, since the current level varies with load condition, it is hard to tune the switching timing diagram to match these two currents. Thus, a passive or an active clamp circuit is still needed.

An active commutation is to control the current of leakage inductance; however, clamping circuits are additionally required. Passive and active clamping circuits have been proposed to suppress the voltage spikes due to the current difference between the current-fed inductor and leakage inductance of the isolation transformer. An *RCD* passive snubber to clamp the voltage, and the energy absorbed in the clamping capacitor is dissipated on the resistor, thus resulting in lower efficiency. A buck con-verter was employed to replace an *RCD* passive snubber.

This paper introduces a flyback snubber to recycle the absorbed energy in the clamping capacitor. The flyback snubber can be operated independently to regulate the voltage of the clamping capacitor; therefore, it can clamp the voltage to a desired level just slightly higher than the voltage across the low-side transformer winding. Since the current does not circulate through the full-bridge switches, their current stresses can be reduced dramatically under heavy-load condition, thus improving system reliability significantly. Additionally, during start-up, the flyback snubber can be controlled to precharge the high-side capacitor, improving feasibility significantly. A bidirectional converter with low-side voltage of 48 V,

IJournals: International Journal of Software & Hardware Research in Engineering
ISSN-2347-4890
Volume 3 Issue 12 December, 2015

high-side voltage of 360 V, and power rating of 1.5 kW has been designed and implemented, from which experimental results have verified the discussed performance.

II. CONFIGURATION AND OPERATION

The proposed isolated bidirectional full-bridge dc–dc converter with a flyback snubber is shown in Fig. 1. The converter is operated with two modes: buck mode and boost mode. Fig. 1 consists of a current-fed switch bridge, a flyback snubber at the low-voltage side, and a voltage-fed bridge at the high-voltage side. Inductor L_m performs output filtering when power flows from the high-voltage side to the batteries, which is denoted as a buck mode. On the other hand, it works in boost mode when power is transferred from the batteries to the high-voltage side. Furthermore, clamp branch capacitor C_C and diode D_C are used to absorb the current difference between current-fed inductor L_m and leakage inductance L_{ll} and L_{lh} of isolation transformer T_X during switching commutation. The flyback snubber can be independently controlled to regulate V_C to the desired value, which is just slightly higher than V_{AB}. Thus, the voltage stress of switches $M1$–$M4$ can be limited to a low level. The major merits of the proposed converter configuration include no spike current circulating through the power switches and clamping the voltage across switches $M1$–$M4$, improving system reliability significantly. Note that high spike current can result in charge migration, over current density, and extra magnetic force, which will deteriorate in MOSFET carrier density, channel width, and wire bonding and, in turn, increase its conduction resistance.

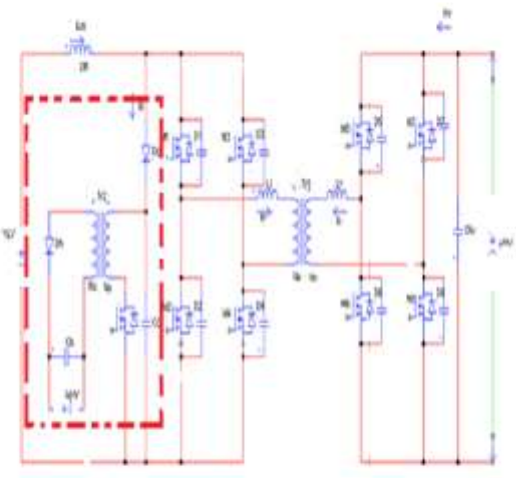

Fig. 1. Isolated bidirectional full-bridge Boost converter with a flyback snubber using zvs technique

A bidirectional dc–dc converter has two types of conversions: step-up conversion (boost mode) and step-down conversion (buck mode). In boost mode, switches M_1–M_4 are controlled, and the body diodes of switches M_5–M_8 are used as a rectifier. In buck mode, switches M_5–M_8 are controlled, and the body diodes of switches M_1–M_4 operate as a rectifier. To simplify the steady-state analysis, several assumptions are made, which are as follows.

1) All components are ideal. The transformer is treated as an ideal transformer associated with leakage inductance.
2) Inductor L_m is large enough to keep current i_L
Constant over a switching period.
3) Clamping capacitor C_C is much larger than parasitic capacitance of switches M_1–M_8.

A. Step-Up Conversion

In boost mode, switches M_1–M_4 are operated like a boost converter, where switch pairs (M_1 , M_2) and (M_3 , M_4) are turned ON to store energy in L_m. At the high-voltage side, the body diodes of switches M_5–M_8 will conduct to transfer power to V_{HV}. When switch pair (M_1 , M_2) or (M_3 , M_4) is switched to (M_1 , M_4) or (M_2 , M_3), the current difference i_C (= $i_L - i_p$) will charge capacitor C_C , and then, raise i_p up to i_L . The clamp branch is mainly used to limit the transient voltage imposed on the current-fed side switches. Moreover, the flyback converter can be controlled to charge the high-voltage-side capacitor to avoid over current. The clamp branch and the flyback snubber are activated during both start-up and regular boost operation modes. A nonphase-shift PWM is used to control the circuit to achieve smooth transition from start-up to regular boost operation mode. Referring to Fig. 1, the average power P_C transferred to C_C can be determined as follows:

$$P_C = 1/2C_C\,[(i_L Z_o)_2 + 2 i_L Z_o V_{C(R)}\,] f_s$$

$$Z_o = \sqrt{L_{eq}/C_C}$$

$$L_{eq} = L_{ll} + L_{lh} N_{2P}/N_{2S}$$

$V_{C(R)}$ stands for a regulated V_C voltage, which is close to (V_{HV}
(N_P /N_S)), f_s is the switching frequency, and L_m _L_{eq}. Power P_C will be transferred to the high-side voltage source through the flyback snubber, and the snubber will regulate clamping capacitor voltage V_C to $V_{C(R)}$ within one switching cycle T_s (=1/f_s). Note that the flyback snubber does not operate over the interval of inductance current i_p increasing toward IL. The processed power P_C by the flyback snubber is typically around 5% of the full-load power for low-voltage applications. With the flyback snubber, the energy absorbed in C_C will not flow through switches M_1–M_4, which can reduce their current stress

dramatically when L_{eq} is significant. Theoretically, it can reduce the current stress from $2i_L$ to i_L . The peak voltage $V_{C\,(P)}$ of V_C will impose on M_1–M_4 and it can be determined as follows:

$$V_{C\,(P)} = IL_{\,(M)}\, Zo + V_{HV} N_p/N_s$$

where $i_{L\,(M)}$ is the maximum inductor current of i_L , which is related to the maximum load condition. Additionally, for reducing conduction loss, the high-side switchesM_5–M_8 are operated with synchronous switching. Reliable operation and high efficiency of the proposed converter are verified on a prototype designed for alternative energy applications.

The operation waveforms of step-up conversion are shown in Fig. 2.Adetailed description of a half-switching cycle operation is shown as follows.

Mode 1 *[$t_0 \le t < t_1$]:* In this mode, all of the four switches M_1–M_4 are turned ON. Inductor L_m is charged by V_{LV}, inductor current i_L increases linearly at a slope of V_{LV}/L_m, and the primary winding of the transformer is short-circuited. The equivalent circuit is shown in Fig. 3(a).

Mode 2 *[$t_1 \le t < t_2$]:* At t_1, M_1 and M_4 remain conducting, while M_2 and M_3 are turned OFF. Clamping diode D_c conducts until the current difference (i_L (t_2) − i_p (t_2)) drops to zero at $t = t_2$. Moreover, the body diodes of switch pair (M_5, M_8) are conducting to transfer power. During this interval, the current difference (i_L (t) − i_p (t)) flows into clamping capacitor C_C. The equivalent circuit is shown in Fig. 3(b).

Mode 3 *[$t_2 \le t < t_3$]:* At t_2 , clamping diode D_c stops conducting, and the flyback snubber starts to operate. At this time, clamping capacitor C_c is discharging, and flyback inductor is storing energy. Switches M_1 and M_4 still stay in the ON state, while M_2 and M_3 remain OFF. The body diodes of switch pair (M_5, M_8) remain ON to transfer power. The equivalent circuit is shown in Fig. 3(c).

Mode 4 *[$t_3 \le t < t_4$]:* At t_3, the energy stored in flyback inductor
is transferred to the high-voltage side. Over this interval, the flyback snubber will operate independently to regulate V_C to $V_{C\,(R)}$. On the other hand, switches M_1 and M_4 and diodes D_5. and D_8 are still conducting to transfer power from V_{LV} to V_{HV} .
The equivalent circuit is shown in Fig. 3(d).

Mode 5 *[$t_4 \le t < t_5$]:* At t_4, capacitor voltage V_C has been regulated to $V_{C\,(R)}$, and the snubber is idle. Over this interval, the main power stage is still transferring power from V_{LV} to V_{HV}. It stops at t_5 and completes a half-switching cycle operation. The equivalent circuit is shown in Fig. 3(e).

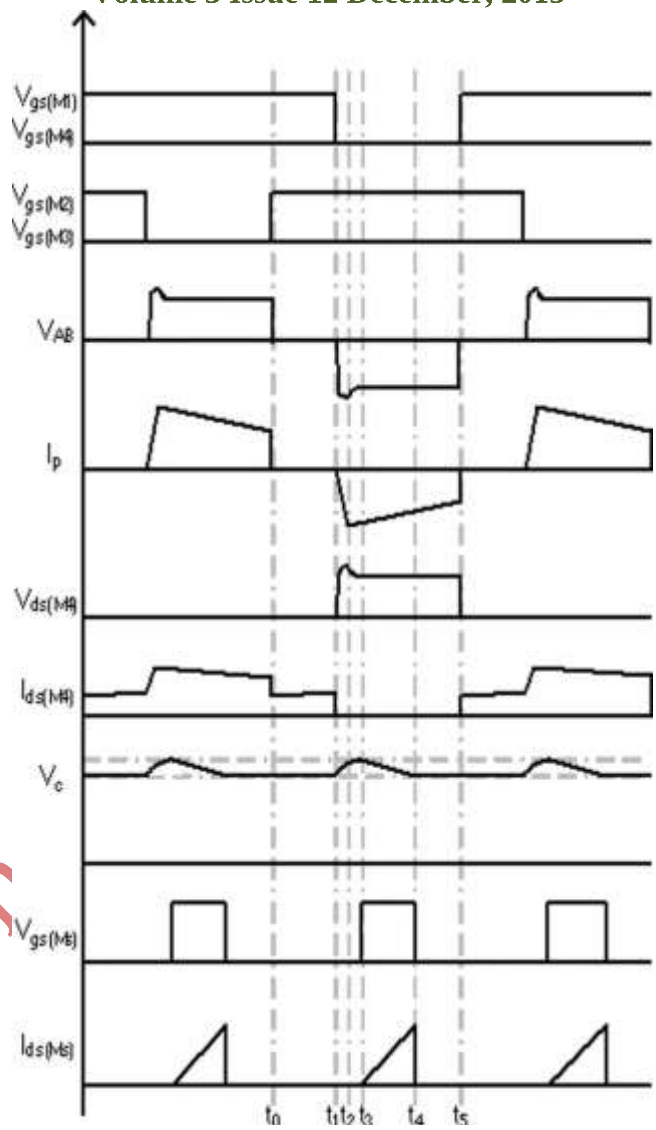

Fig. 2. Operation waveforms of step-up conversion

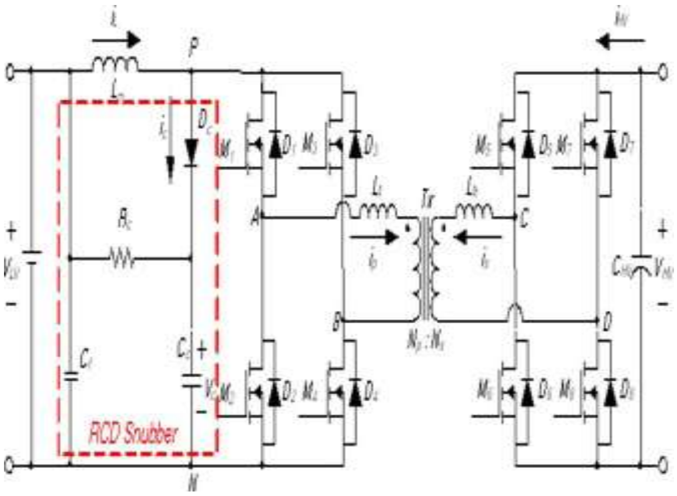

Fig. 3. Isolated bidirectional full-bridge boost converter with an *RCD* passive snubber

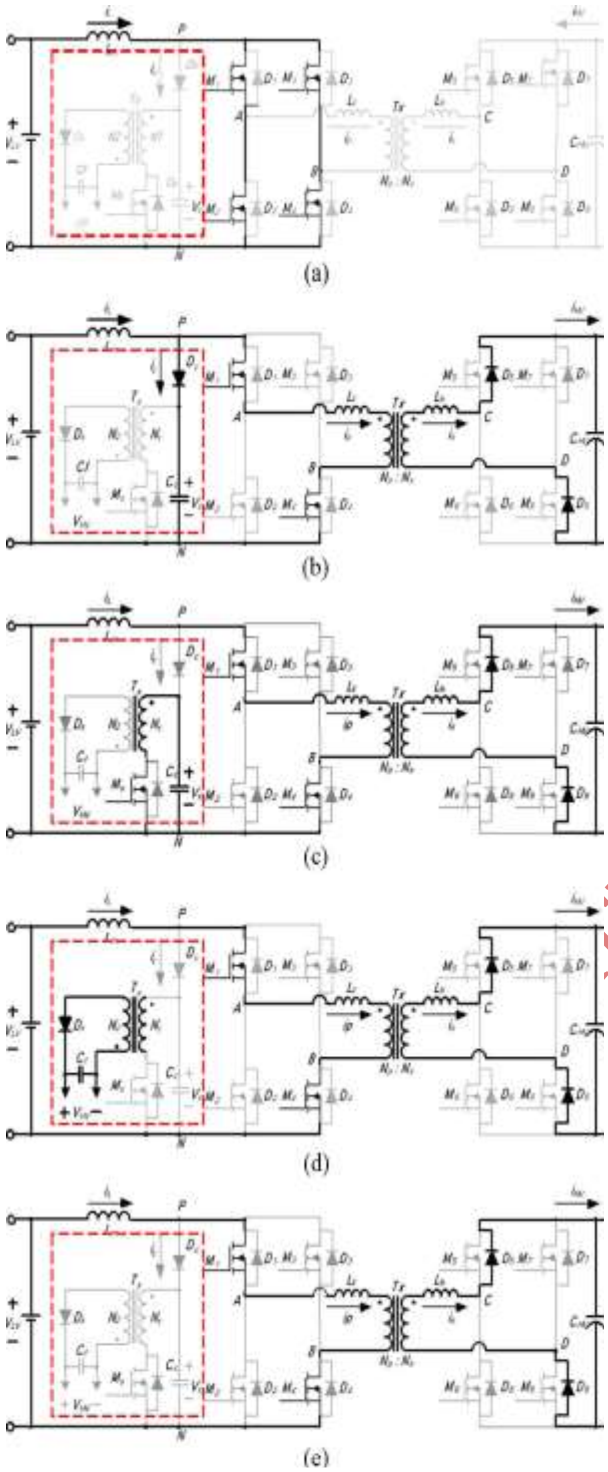

Fig. 4. Operation modes of step-up conversion. (a) Mode 1. (b) Mode 2. (c)Mode 3. (d) Mode 4. (e) Mode 5.

B. Clamping Capacitor

For absorbing the energy stored in the leakage inductance a nd to limit the capacitor voltage to a specified minimal value *Vc, l*, capacitance *Cc* has to satisfy the following inequality:

C. Flyback Converter

In the interval of $t_1 \le t \le t_2$, the high transient voltage occurs inevitably in boost mode, which could be suppressed by the clamp branch (D_c, C_c). The energy stored in capacitor C_c is transferred to the high-voltage side via a flyback converter. The regulated voltage level of the flyback converter is set between 110%–120% of the steady-state voltage at the low-voltage side.

TABLE I
SPECIFICATIONS OF THE PROTOTYPE

Low-side Voltage	V_{LV} = 48 V
High-side Voltage	V_{HV} = 360 V
Output Power	$P_{o(max)}$ = 1.5 kW
Switching Frequency	f_s = 25 kHz
Turns Ratio	$N = N_p / N_s = 4.26$
Leakage Inductance	L_{ll} = 0.5 μH, L_{lh} = 9 μH
Current-fed Inductor	L_m = 500 μH
Clamping Capacitor	C_C = 1 μF
Low-side Switches	$M_1 \sim M_4$: IRFB4321PbF (150V/83A) ×2
Low-side Capacitor	C_{LV} : 100 μF
Low-side Inductor	L_m : 500 μH
High-side Switches	$M_5 \sim M_8$: IRFP26N60LPBF (600V/26A)
High-side Capacitor	C_{HV} : 470μF×2

The conventional non-isolated boost converter topology has been extensively used in various ac–dc and dc–dc applications. In fact, the front end of today's ac–dc power supplies with power-factor correction (PFC) is almost exclusively implemented with the boost topology. The boost topology is also used in numerous battery-powered applications to generate a high output voltage from a relatively low battery voltage. However in some applications, it may be advantageous to use a boost converter with a galvanically isolated input and output. For example, fault tolerant power systems that use a dual ac-input architecture can be implemented with isolated boost converters. In fact, the isolated-boost-converter implementation offers a reduced number of components compared to the implementations with nonisolated boost converters in applications which require dual ac input. Also, in applications where a power supply with both ac and dc inputs is required, the isolated boost converter can be applied to provide safety-required isolation between the inputs. So far, a number of boost topologies utilizing an isolation transformer have been proposed.

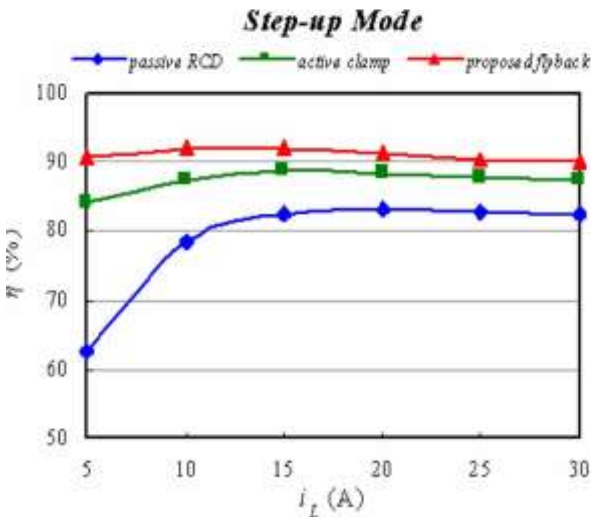

Fig 5. Plots of conversion efficiency of the bidirectional converter with various snubber operated in step-up mode.

EXPERIMENTAL RESULTS

For comparison, three prototypes, the dual full-bridge converters with an *RCD* passive snubber, an active clamping circuit, and the proposed flyback snubber, were built and tested. The one with an *RCD* passive snubber is shown in Fig. 7, and Fig. 8 shows prototype with an active clamping circuit. A block diagram of the isolated bidirectional full-bridge dc–dc converter with the proposed flyback snubber is shown in above Fig. Describing the signal flow and linkage between the power stage and the controller. It was implemented with the specifications listed in Table I, and the circuit diagram shown in Fig. 1. Note that the picture of a 1.5-kW experimental prototype with the proposed configuration is shown in Fig. 10. A battery module working at the low-voltage side is employed as an energy-storage element, whose voltage rating is 48 V. The high-voltage side is 360 V.

Stimulation Results

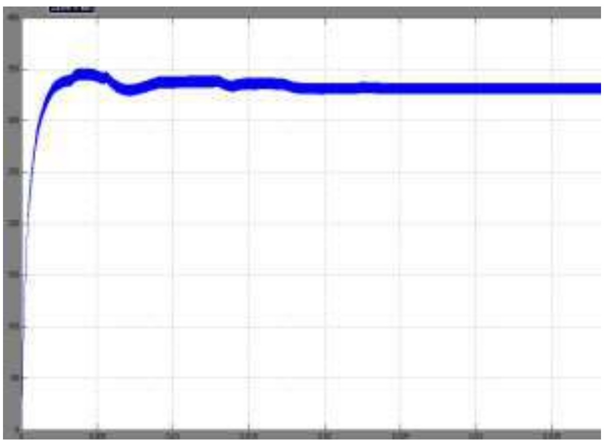

Fig 6. Voltage waveform of the bidirectional converter with flyback snubber

CONCLUSION

This paper has presented an isolated bidirectional full-bridge dc–dc converter with a flyback snubber for high-power applications. The flyback snubber can alleviate the voltage spike caused by the current difference between the current-fed inductor and leakage inductance of the isolation transformer, and can reduce the current flowing through the active switches at the current fed side by 50%. Since the current does not circulate through the full-bridge switches, their current stresses can be reduced dramatically under heavy-load condition, thus improving system reliability significantly. The flyback snubber can be also controlled to achieve a soft start-up feature. It has been successful in suppressing inrush current which is usually found in a boost-mode start-up transition. A 1.5-kW isolated full-bridge bidirectional dc–dc converter with a flyback snubber has been implemented to verify its feasibility.

REFERENCES

[1] H.Bai andC.Mi, "Eliminate reactive power and increase system efficiency of isolated bidirectional dual-active-bridge DC-DC converters using novel dual-phase-shift control," *IEEE Trans. Power Electron.*, vol. 23, no. 6, pp. 2905–2914, Dec. 2008.

[2] B. Bai, C. Mi, and S. Gargies, "The short-time-scale transient processes in high-voltage and high-power isolated bidirectional DC-
DC converters," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2648–2656, Nov. 2008.

[3] C. Zhao, S. D. Round, and J.W.Kolar, "An isolated three-port bidirectional DC-DC converter with decoupled power flow management," IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2443–2453, Sep. 2008.

[4] R. Huang and S. K. Mazumder, "A soft-switching scheme for an isolated DC/DC converter with pulsating DC output for a three-phase highfrequency-link PWM converter," IEEE Trans. Power Electron., vol. 24, no. 10, pp. 2276–2288, Oct. 2009.

[5] H. Xiao and S. Xie, "A ZVS bidirectional dc-dc converter with phased shift plus PWM control scheme," IEEE Trans. Power Electron., vol. 23, no. 2, pp. 813–823, Mar. 2008.

[6] G. Ma, W. Qu, and Y. Liu, "A zero-voltage-switching bidirectional DC-DC converter with state analysis and soft-switching-oriented design

consideration," IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 2174–2184, Jun. 2009.

[7] F. Krismer and J. W. Kolar, "Accurate small-signal model for the digital control of an automotive bidirectional dual active bridge," IEEE Trans. Power Electron., vol. 24, no. 12, pp. 2756–2768, Dec. 2009.

[8] F. Barone, "A lightweight inverter for off-grid and grid-connected systems," in Proc. Photovoltaic Spec. Conf., 1994, vol. 1, pp. 917–920.

[9] T. Riemann, S. Szeponik, and G. Berger, "A novel control principle of bi-directional DC-DC power conversion," in Proc. Power Electron. Spec .Conf., 1997, vol. 2, pp. 978–984.

[10] K.Wang, C. Y. Lin, L. Zhu, D. Qu, F. C. Lee, and J. S. Lai, "Bi- directional DC to DC converters for fuel cell systems," in Proc. Power Electron. Transp., 1998, pp. 47–51.

[11] H. L. Chan, K. W. E. Cheng, and D. Sutanto, "A phase-shift controlled bi-directional DC-DC converter," in Proc. Circuits Syst., 1999, vol. 2, pp. 723–726.

[12] S.Yujin and P.N. Enjeti, "A newsoft switching technique for bi-directional power flow, full-bridge DC-DC converter," in Proc. Ind. Appl.Conf., 2002, vol. 4, pp. 2314–2319.

[13] O. Garcia, L. A. Flores, J. A. Oliver, J. A. Cobos, and J. De la pena, "Bi-directional DC-DC converter for hybrid vehicles," in Proc. Power Electron. Spec. Conf., 2005, pp. 1881–1886.

[14] L. Zhu, "A novel soft-commutating isolated boost full-bridge ZVS-PWM DC-DC converter for bidirectional high power applications," IEEE Trans. Power Electron., vol. 21, no. 2, pp. 422–429, Mar. 2006.

[15] H. Krishnaswami and N. Mohan, "A current-fed three-port bi-directional DC-DC converter," in Proc. Telecommun. Energy Conf., 2007, pp. 523–526.